NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

NUCLEATE POOL BOILING OF R-114 AND R-114/OIL MIXTURES FROM SINGLE ENHANCED TUBES

by

Dean C. Sugiyama

SEPTEMBER 1991

Thesis Advisor: Paul J. Marto
Thesis Co-Advisor: Stephen B. Memory

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release: Distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School — 6b. OFFICE SYMBOL (If applicable) ME	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State and ZIP Code) Monterey, CA 93943-5000	7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBER PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
NUCLEATE POOL BOILING OF R-114 AND R-114/OIL MIXTURES FROM SINGLE ENHANCED TUBES

12. PERSONAL AUTHORS
DEAN C. SUGIYAMA

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Master's Thesis	FROM______ TO______	SEPTEMBER 1991	228

16. SUPPLEMENTARY NOTATION
The views expressed are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block numbers)
FIELD	GROUP	SUB-GROUP	heat transfer, nucleate pool boiling, R-114/oil mixtures

19. ABSTRACT (Continue on reverse if necessary and identify by block numbers)

Nucleate pool boiling heat transfer is an integral part of any vapor-compression refrigeration cycle. With a view to improving overall cycle efficiency, the heat transfer performance in the evaporator can be improved by using enhanced boiling surfaces. This thesis looks at the pool boiling characteristics of R-114 (presently used in large shipboard AC systems) from 10 enhanced single copper tubes and compares performance with a smooth copper tube. Since small amounts of oil escape into the refrigerant as it passes through the compressor of a refrigeration system, tests have also been conducted with up to 10% (by weight) of a miscible oil to see what effect this may have on overall evaporator performance.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION	
XX UNCLASSIFIED/UNLIMITED __ SAME AS RPT __ DTIC USERS	unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Paul J. Marto	(408) 646-3241	ME/Mx

DD Form 1473, JUN 86 — Previous editions are obsolete. — SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

S/N 0102-LF-014-6603

Approved for public release: Distribution is unlimited

Nucleate Pool Boiling of R-114 and R-114/Oil Mixtures from Single Enhanced Tubes

by

Dean C. Sugiyama
Lieutenant, United States Navy
B.A., University of California of Berkeley, 1985

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

SEPTEMBER 1991

for A.J. Healey, Chairman
Department of Mechanical Engineering

ABSTRACT

Nucleate pool boiling heat transfer is an integral part of any vapor-compression refrigeration cycle. With a view to improving overall cycle efficiency, the heat transfer performance in the evaporator can be improved by using enhanced boiling surfaces. This thesis looks at the pool boiling characteristics of R-114 (presently used in large shipboard AC systems) from 10 enhanced single copper tubes and compares performance with a smooth copper tube. Since small amounts of oil escape into the refrigerant as it passes through the compressor of a refrigeration system, tests have also been conducted with up to 10% (by weight) of a miscible oil to see what effect this may have on overall evaporator performance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

A	area
Ab	tube outside surface area of active boiling section
Ac	cross-sectional area of tube
Cp	specific heat
D	diameter
Di	tube inside diameter
Do	tube outside diameter
D1	diameter at the position of the thermocouple
D2	outer diameter of the boiling tube
g	gravitational acceleration
h	heat-transfer coefficient
hfg	latent heat of vaporization
I	current
Is	current reading by AC Current Sensor
k	thermal conductivity of liquid
kc	thermal conductivity of copper
L	active boiling tube length
Lu	non-boiling length of the test tube
Nu	Nusselt number
p	tube outside wall perimeter
Pr	Prandtl Number
Q	heat-transfer rate from boiling surface
Qf	heat-transfer rate through one nonboiling end
Qh	heat-transfer rate from cartridge heater
q"	heat flux
Ra	Rayleigh number
T	temperature
Tavg	average wall temperature at the thermocouple location
Tc	critical temperature
Tf	film temperature

Tn	temperature of the thermocouple location
Tsat	saturation temperature
Two	outer wall temperature of the boiling test tube
V	voltage across the cartridge heater
Vs	voltage reading by AC-DC true RMS converter
α	thermal diffusivity
β	volumetric thermal expansion coefficient
δ	uncertainty in measurement and calibration
θ	superheat
μ	dynamic viscosity
ν	kinematic viscosity
ρ	density

I. INTRODUCTION

A. BACKGROUND

The United States Navy currently uses R-114 in approximately 950 centrifugal chilled-water air-conditioning plants. Ongoing efforts to reduce the cost and increase the efficiency of these plants have been directed towards the use of enhanced heat-transfer tube surfaces and alternative refrigerants. The choice of alternative refrigerant must be "ozone friendly." A possible "drop in" replacement for R-114 has been identified: R-124. Studies of the boiling performance of R-124 would be complemented well by a baseline of data on R-114.

B. ADVANTAGES OF USING R-114

The use of R-114 in Naval applications has been driven by concerns for both cost and safety. R-114 operates under moderate pressures and has one of the lowest toxicity ratings among all refrigerants. System components are significantly smaller and more lightweight which is desirable for shipboard use and maintenance. While R-11 is widely used in industry, its operating requirements make it unsuitable onboard ship. R-11 operates under vacuum and has a tendency to absorb ambient moisture. This acidic combination of R-11 and moisture attacks tubes and causes corrosion. R-114 is considerably stable to

heat and may be used with all standard ferrous and non-ferrous metals except zinc, magnesium and aluminum alloys containing appreciable amounts of zinc and magnesium. The thermophysical properties of R-114 are provided in Appendix A.

C. THESIS OBJECTIVES

Safety requirements for future studies of R-124 necessitated the disassembly and relocation of the single-tube apparatus described in this thesis. Past studies using the apparatus have varied considerably in operating procedure, thus it became desirable to establish a consistent operating procedure in the acquisition of all data on R-114. With the foregoing discussion in mind, the objectives of this thesis were to:

1. Relocate and calibrate the single tube apparatus.
2. Operate the apparatus to produce repeatable data and confirm earlier results.
3. Obtain boiling data for R-114 and R-114/oil mixtures on ten tube surfaces to be used as a database for future studies on enhanced surfaces and alternative "ozone safe" refrigerants.

II. REVIEW OF REFRIGERANT AND REFRIGERANT/OIL POOL BOILING BEHAVIOR

A. NUCLEATE POOL BOILING PERFORMANCE OF PURE R-114

The heat-transfer performance of pure R-114 on a smooth tube in the natural convection region of its boiling curve can be reasonably predicted using well known correlations, Churchill and Chu [Ref. 1] and more recently Churchill and Usagi [Ref. 2]. A lack of complete understanding of the nucleate boiling mechanism makes it more difficult the to predict the performance in the nucleate boiling region. Well known correlations, such as that by Rohsenow [Ref. 1], and more recently, Stephan-Adelsalam [Ref. 3] are approximate and should be compared with experimental data whenever possible.

Many pool-boiling experiments have been carried out on finned tubes (typically 19 to 40 fpi) in pure refrigerants. For various refrigerants, tube material, fin density and system pressure, typical enhancements in the heat transfer coefficient (over smooth tubes values) of up to 3 have been reported, the refrigerants with better wetting characteristics giving the greater enhancement. Interestingly enough, the boiling performance of finned tubes becomes very similar to that of smooth tubes, if the heat flux is recalculated on the basis of total outside wetted surface area (rather than root diameter, which is commonly used).

Re-entrant cavity surfaces differ from finned surfaces in that they provide a higher density of stable nucleation sites with minimum wall superheat (Yilmaz and Westwater [Ref. 4] Carnavos [Ref. 5], Marto and Lepere [Ref. 6] and Wanniarachchi *et al.* [Refs. 7, 8]). Significant improvements in heat transfer over both finned and smooth tubes have been shown for re-entrant cavity surfaces.

Boiling enhancements were as large as 14.6 and 6.4 for High Flux and Turbo-B tubes, respectively, compared to smooth tube data.

Webb [Ref. 9] stated that the key to the high performance of the re-entrant surfaces can be attributed to three factors: (1) re-entrant cavity within a critical size range, (2) interconnected cavities, and (3) nucleation sites of a re-entrant shape. If the cavities are interconnected, adjacent cavities can activate each other. Re-entrant cavities provide a stable vapor trap, which can remain active at low values of superheat.

During nucleate boiling of R-114 at one atmosphere, Wanniarachchi *et al.* [Refs. 7 and 8] reported data for four enhanced tubes: a porous coated High Flux, Thermoexcel-E, Thermoexcel-HE and a 26 fpi GEWA-T. Enhancements of 9.1, 8.2, 6,8 and 4.4 respectively were obtained at a heat flux of 30 kW/m^2. The enhancement provided by the High Flux tube reduced to 6 at higher fluxes of about 100 kW/m^2, but it still outperformed the other three tubes. At heat fluxes below 18

kW/m^2, both the Thermoexcel tubes performed the best. However, they noted that the uncertainty in the data increased as both superheat and heat flux decreased.

Whereas the majority of pool-boiling experiments use electrically heat tubes, McManus *et al.* [Ref. 10] used hot water to heat both a High Flux and Turbo-B tube in a pool of R-114. The range of heat flux was very limited. However, at a heat flux of 40 Kw/m^2, enhancements of 14.6 and 6.4 respectively, were obtained over smooth tube values.

B. NUCLEATE POOL BOILING PERFORMANCE OF REFRIGERANT-OIL MIXTURES

Most refrigeration systems use hermetically sealed compressors which allow small quantities of oil to escape into the working fluid. This oil tends to collect in the flooded evaporator, giving up to 10% oil in some cases. The nucleate pool boiling mechanism is further complicated when a less volatile component, such as miscible refrigerant oil, is mixed with the refrigerant. Design and modelling rely heavily on accurate experimental data covering a wide range of operating conditions.

Compared with pure refrigerants, there is little data for boiling of refrigerant/oil mixtures from finned surfaces. Chaddock [Ref. 11] gives a thorough summary of such mixtures through 1975. Sauer *et al.* [Ref. 12] report data from 19 fpi copper tube using R-11 with two different oils. For oil

concentrations less than 3%, their results indicated no difference in boiling heat transfer performance from that of the pure refrigerant. For oil concentrations greater than 5%, significant degradation in performance was shown. They concluded that finned tubes performed best at low wall superheats and that this performance was not impaired by up to 3% oil addition.

Murphy [Ref. 13] carried out experiments on a 26 and 40 fpi tube using R-114/oil mixtures. Similar to Sauer [Ref. 11], no difference in performance was observed for oil concentrations up to 3%. Indeed in some cases, at a higher heat flux of about 100 kW/m^2, a 3% oil concentration showed a small <u>increase</u> in performance over the pure refrigerant case. The mechanism for this improvement is not well understood, but has been found by a number of investigators for both flow and pool boiling. At a 10% oil concentration, both tubes exhibited a 30% degradation in performance versus the pure refrigerant case, which agreed with Sauer's findings.

Wanniarachi *et al.* [Refs. 7, 8] reported the performance of High Flux, Thermoexcel-E, Thermoexcel-HE and GEWA-T tubes in R-114/oil mixtures at one atmosphere. Oil concentrations up to 10% (by weight) were studied. A marked increase in the wall superheat values required for the incipience of nucleate boiling was observed in the presence of oil. Enhancements mentioned previously for pure R-114 were reduced at a 3% oil concentration, to 7.5, 5.5, 5.5 and 3.8 respectively. With 10%

oil concentrations, further reductions to 5.5, 3.8, 3,8 and 2.9 were observed. At the highest heat fluxes (> 45 kW/m^2) and for oil concentrations greater than 6%, the performance of the High Flux tube degraded at a rate that left the GEWA-T tube as the best performer.

III. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. OVERVIEW OF THE SYSTEM

Wanniarachchi *et al.* [Ref. 7], Murphy [Ref. 13] and Karasabun [Ref. 14] provide complete details of the original apparatus used in previous studies. Disassembly of the original apparatus to facilitate relocation and subsequent modifications to meet present site requirements justify a full description of the apparatus. The original R-12 cooling subsystem was supplanted by a more efficient R-502 system. The auxiliary heaters and plastic shield were removed, however power extensions were kept available for their use in future studies. The Variac power supply to the tube heater was calibrated and emplaced into a panel enclosure. See Appendix D, Apparatus Calibration for more details. A more modern Hewlet-Packard Computer/Data Acquisition system was installed and the data reduction program DRP8 was updated to account for variac calibration and program language changes.

An overall schematic representation of the experimental apparatus is shown in Figure 3.1, and a photograph is shown in Figure 3.2. The apparatus essentially consists of 8 (components: 1) a Pyrex-glass tee for the pool boiling of the R-114 liquid, "the evaporator"; (2) a Pyrex-glass tee for the condensing of the R-114 vapor, "the condenser"; (3) a R-114

liquid reservoir; (4) a refrigerant/oil subsystem composed of an oil reservoir and a graduated oil cylinder; (5) a cooling subsystem composed of a 1/2 ton R-502 refrigeration plant, 2 positive displacement pumps and a 30 gallon water/ethylene glycol sump; (6) a vacuum pump; (7) a data acquisition and instrumentation system; (8) an aluminum/Plexi-glass framework within which components (1) through (4) were housed.

The apparatus was operated as follows: liquid R-114 was boiled in the evaporator (1), passed as vapor through the aluminum L-shaped connection and condensed in the condenser (2). R-114 condensate was returned by gravity via the distribution tube to the condenser. The R-502 refrigeration plant maintained the water/ethylene glycol mixture in the sump between -12 and -18 °C. Cooling of the sump was accomplished by a countercurrent flow heat exchanger through which an 8-gpm turbine-type pump recirculated the water/ethylene glycol mixture. An identical positive displacement pump circulated the cooled mixture through the copper condensing coils in the condenser via the control valve VC.

Prior to dismantling the evaporator in order to change out boiling tubes, the liquid R-114 was boiled out of the evaporator, condensed on the coils of the condenser then recovered to the R-114 liquid reservoir rather than returned to the evaporator. Upon reassembly, the evaporator was recharged with liquid R-114 by gravity from the reservoir. The

level in the reservoir could be topped off via the condenser from an external supply cylinder through valve V10.

Exact quantities of oil could be added to the liquid R-114 in the lower glass tee from the graduated cylinder (5) by gravity. The graduated cylinder was filled with oil by gravity from the oil reservoir through valves V14 and V2. Refilling the oil reservoir was done through valve V3 located at the top of the framework. All oil left over from the recovery of the liquid R-114 was drained out of the lower glass tee and disposed of.

The boiling tube was mounted horizontally in the evaporator and held in place by Teflon bushings with O-ring inserts. The whole system was connected to the vacuum pump (6) through valve V8 in order to remove noncondensible gases. A relief valve mounted on the aluminum L connection was set to a gage pressure limit of 20 psi, which is 50% less than the manufacturer-recommended working pressure limit of the Pyrex glass tees. All connections were assembled with Swagelok fittings sealed with Teflon ferrules to ensure leak tightness. Copper tubing of 3/8 inch diameter was used for all piping, except in the oil section, where 1/4 inch copper tubing was used.

B. BOILING TEST SECTION

1. Evaporator

The evaporator is a T-shaped container made of Corning Pyrex glass. Figure 3.3 shows a schematic of the evaporator with dimensions. Pyrex glass has several advantages: it is corrosion-resistent, transparent, has a smooth interior surface (this minimized nucleate boiling at the inner surface of the container) and is stronger with temperature and pressure variations compared to ordinary glass. The manufacturer recommended operating pressure limit of the Pyrex glass tee is 30 psi gage. Each end of the evaporator was fitted with a cast-iron flange and a gasket. A detailed sketch of the cast-iron flange is shown in Figure 3.3 also. To reduce weight upon the glass tees, two aluminum flanges, 210 mm in diameter and 12.7 mm in thickness, were bolted to the cast-iron flanges. All fittings were connected through the aluminum flanges to the Pyrex-glass evaporator.

2. Test Tube

A schematic drawing of the test tube is shown in Figure 3.4. The boiling tube was held in place by two Teflon bushings, which were attached to the aluminum flanges at both ends of the T-shaped evaporator. Four studs were used in order to attach the Teflon bushing on the aluminum flange. The Teflon bushing and both ends of the test tube were sealed by

means of two viton O-rings that were placed between the aluminum flange and the Teflon plug at each end.

3. Boiling Tubes

A smooth, hard-copper tube, 15.9 mm (5/8 in.) in outer diameter, 12.7 mm (1/2 in) in inside diameter and 431.3 mm (17 in.) in length, was used to provide comparison data for the nucleate pool boiling heat-transfer performance of the enhanced tubes tested. All of the tubes were heated and instrumented identically. Dimensions of each tube are provided in Table V of Appendix E, Sample Calculations. Wanniarachchi *et al.* [Refs. 8, 9] and Murphy [Ref. 14] provide complete details of the tube surfaces.

The ten tubes tested were:

1. Smooth
2. GEWA-K 26 fpi (Figure 3.5)
3. GEWA-K 40 fpi (Figure 3.5)
4. GEWA-T 19 fpi (Figure 3.5)
5. GEWA-T 26 fpi (Figure 3.5)
6. GEWA-YX 26 fpi (Figure 3.6)
7. High Flux (Figure 3.7)
8. Thermoexcel-HE (Figure 3.8)
9. Thermoexcel-E (Figure 3.9)
10. Turbo-B (Figure 3.9)

The heater was a 1000-Watt, 240-Volt stainless-steel cartridge, 6.35 mm (1/4 in.) in outer diameter and 203.2 mm (8 in) in length. It was inserted into a copper sleeve, which was 1/4 inch in inside diameter, 1/2 inch in outer diameter and 8 inches in length. In order to provide a uniform heat flux, the cartridge heater and the copper sleeve were soldered together. To minimize the thermal contact resistence, the copper sleeve was then tinned (the cartridge heater was used to maintain the solder in molten state) and inserted as a unit into the middle portion of the test tube. The active boiling length of the test tube was therefore eight inches in the middle portion of the boiling tube. In order to compute the actual average heat flux in the heated portion of the tube, a suitable correction was applied for the heat lost by natural convection out both ends. See Appendix E, Sample Calculation for details.

To measure the wall surface temperature of the boiling tube, 8 thermocouples (Type-T Teflon coated copper-constantan; 0.01 inch in diameter) were inserted into eight grooves machined on the outside of the copper sleeve. As shown in Figure 3.10, these thermocouples were located at different axial and circumferential locations. The exact locations of the thermocouples and dimensions of the thermocouple grooves are given in Figure 3.10. All the thermocouple grooves were axially machined from the location of the thermocouple hot junctions to the nearest end of the copper sleeve.

C. CONDENSER SECTION

The condenser was also a T-shaped container made of Corning Pyrex glass. It was identical to the evaporator. The position of the condenser can be seen in Figure 3.1. R-114 was condensed on a helical copper coil, which was inserted in the Pyrex-glass condenser. Copper tubing (3/8 inch outer diameter) was fabricated into a three inch diameter coil. The active condensation length was estimated to be 15 ft.

The top portion of the condenser was connected to a portable, mechanical vacuum pump to remove noncondensible gases from the apparatus. The bottom of the condenser was connected to the evaporator via valve V5 in order to return the condensed R-114 liquid to either the evaporator or the reservoir. The coolant, i.e., water/ethylene glycol mixture, entered from the top portion of the condenser. The condenser was placed vertically and connected to the vapor outlet of the evaporator using a fabricated, L-shaped aluminum tube, two inches in diameter. A Bourdon gage with a range up to a gage pressure of 150 psi and a relief valve which was set to 20 psi gage were mounted on the L-tube.

D. OIL ADDING SECTION

To study the boiling performance of R-114/oil mixtures, a cylindrical aluminum oil reservoir, 6 inches in diameter and 6 inches in height, and a graduated glass oil cylinder were installed above the evaporator as shown in Figure 3.1. The

graduated cylinder was 355 mm in length and had a diameter of 25.4 mm. A resolution of 0.5 ml was achieved with the graduated cylinder. The oil reservoir was connected to the oil cylinder through valves V14 and V2. Refilling the oil reservoir was accomplished through valve V3 located on top of the reservoir. The addition of oil into the evaporator was achieved through V1 by gravity. The oil cylinder was refilled by gravity from the oil reservoir located above.

E. COOLING SECTION

1. Water-Ethylene Glycol Mixture Tank

In order to store the water-ethylene glycol mixture, a special tank was manufactured. The total volume of the tank was 9243 in^3 (18.84 in x 18.84 in x 26.04 in) and it was made of 0.5 inch thick Plexiglas sheet. All sides of the tank were glued together with methylene chloride solution. The joints were held together with small screws for extra strength. The low thermal conductivity of Plexiglas was especially suited to minimize heat transfer (from room to water-ethylene glycol mixture) through the tank walls. The tank was placed on top of square wood platform on the floor and all sides were insulated with 7/8 in thick rubber sheets. The cooling mixture contained 13 gallons of ethylene-glycol and 25 gallons of distilled water. The freezing point of this mixture was about -25 deg C.

2. R-502 Refrigeration Plant

A 1/2 ton R-502 refrigeration plant was installed to cool the water/ethylene glycol mixture. Figure 3.12 shows a schematic of the R-502 refrigeration plant. It consists of a compact-type, air-cooled condenser, a compressor, a receiver, a filter-drier unit, a pressure regulator, a temperature control switch and a thermostatic expansion valve. The evaporator of the R-502 refrigeration plant was constructed using a 3.8 inch copper tube which was run through a countercurrent heat exchanger opposite the water-ethylene glycol mixture. The temperature of the water/ethylene glycol mixture was controlled by both a thermostatic expansion valve and a temperature control switch. The R-502 refrigeration plant was adjusted to keep the temperature of the cooling liquid at about -17 deg C.

3. Pump and Control Valve

An 8 gpm, 115 VAS Burks turbine-type, positive-displacement pump was installed on the floor and the 1 inch diameter suction side of the pump was directly connected to the water/ethylene glycol tank. Cooling liquid was pumped from the tank to the condenser through the control valve VC. Also, a by-pass valve V9 was placed before the control valve VC on the discharge line. The use of the by-pass line served two important purposes: (1) it avoided overloading the pump in the event valve VC is completely closed, and (2) it provided

proper mixing for the "warm" stream returning from the condenser. The by-pass valve required adjustment only at the highest heat fluxes to 'satisfy' proper cooling of the condenser.

F. R-114 RESERVOIR

An aluminum cylindrical reservoir, 9 inches in diameter and 10 inches in height, was placed vertically between the evaporator and condenser in order to store R-114 as a liquid. The liquid level of the R-114 could be observed by means of a sight glass attached on the reservoir. The R-114 reservoir was connected to the vapor line through valve V7 and to the liquid line through valve V6. See Figure 3.1 for the arrangement of the reservoir.

G. CHAMBER

An aluminum frame (42.13 in x 20.07 in x 24.02 in) was constructed to locate all the parts of the apparatus, except the cooling section. All four vertical sides of the frame were covered with 1/2 inch thick Plexiglas sheets and both left and right sides were provided with hinges to enable easy access to the components of the apparatus. Aluminum and plywood plates were used to cover the bottom and top sides of the frame, respectively. The valve bodies of V1 through V8 were placed inside of the front Plexiglass box. The whole frame was placed

above the water-ethylene glycol tank with aluminum supports so that the system was very compact.

One of the main advantages of this chamber was that the temperature surrounding the evaporator could be reduced relative to the ambient temperature. Also, in case of emergency, the thick Plexiglas chamber provides a safety barrier to personnel and data acquisition equipment.

H. INSTRUMENTATION

1. Power Measurement

A 240 volt AC source was used as the power supply, and it was adjusted by a variac in the range of 0-220 volts and 0-5 amperes according to the desired heat flux at the surface of the boiling tube. Power input to the boiling tube was measured with an AC current inductive sensor (output in volts) and a voltage sensor directly coupled to the variac output. The voltage sensor was run through a AC-DC true R.M.S. converter which output a proportional signal in volts. Figure 3.12 shows a schematic representation of the power-measurement setup. Both the AC current sensor and the AC-DC true R.M.S converter were connected to the data acquisition/control unit.

2. Temperature Measurement

Various temperatures were monitored throughout the system to include:

1. Boiling tube wall (8 thermocouples at various longitudinal and circumferential positions)

2. Liquid temperature (one thermocouple)

3. Vapor temperature (two thermocouples), and

4. Water/ethylene glycol mixture temperature (one thermocouple)

The locations of the wall thermocouples in the sleeve of the boiling tube are shown in Figure 3.5. The liquid and vapor thermocouples were inserted into the three specially manufactured thermocouple housings. Figure 3.14 shows a schematic of these thermocouple housings. The stainless-steel portion minimizes (owing to low thermal conductivity) errors resulting from the axial conduction of heat from the surroundings. The copper tip of the housing helps to minimize the temperature drop from the area being measured to the thermocouple location (owing to the high thermal conductivity of copper).

All the temperature measurements were accomplished by 30 gage copper-constantan thermocouples. Each thermocouple measurement was read directly by a Hewlett-Packard 3497A data acquisition system, which was controlled by a Hewlett-Packard 9826 computer. Each thermocouple was scanned twenty times over 5 seconds and the readings averaged to obtain a more accurate measurement.

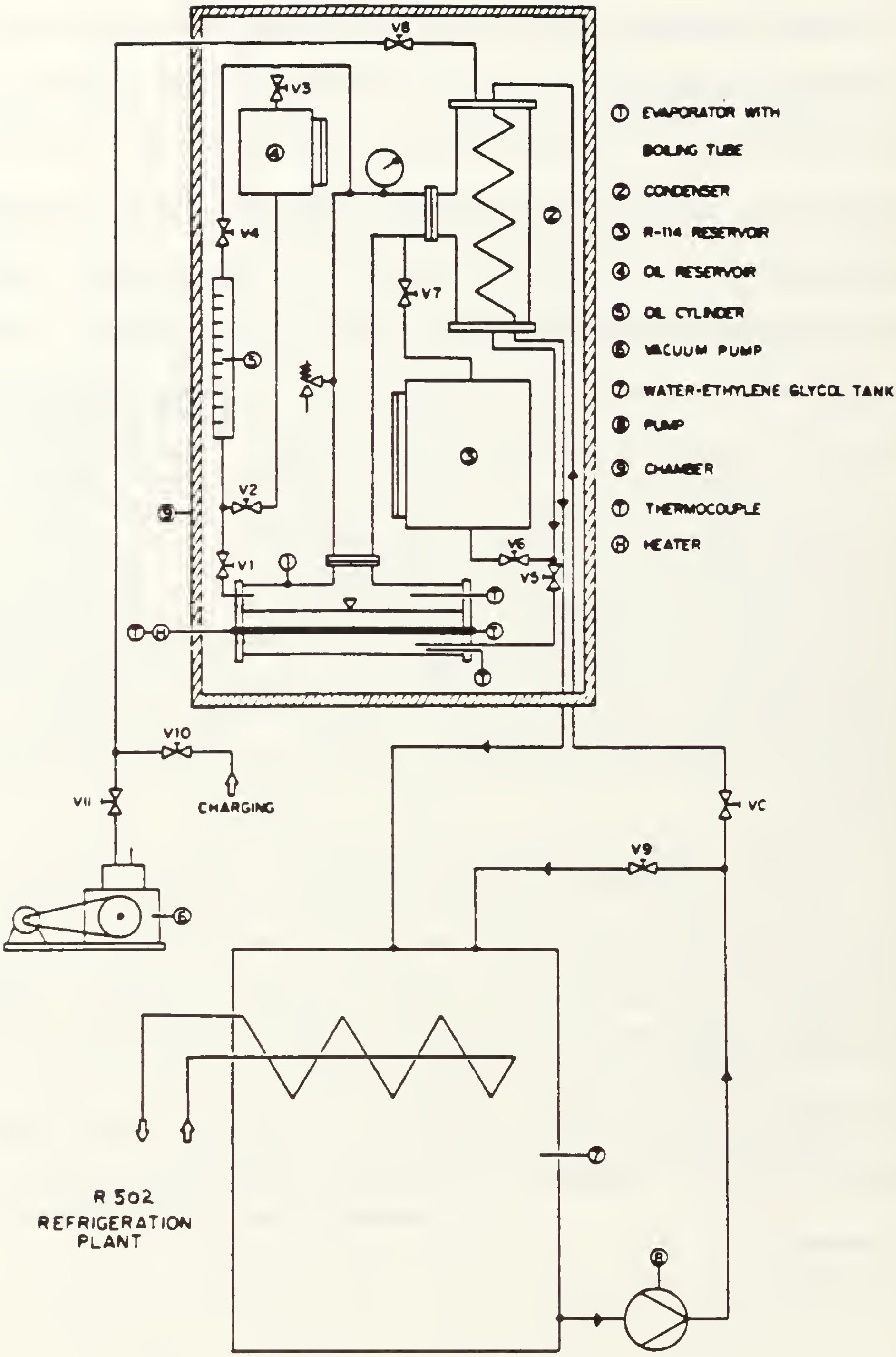


Figure 3.1 Schematic of Single Tube Apparatus

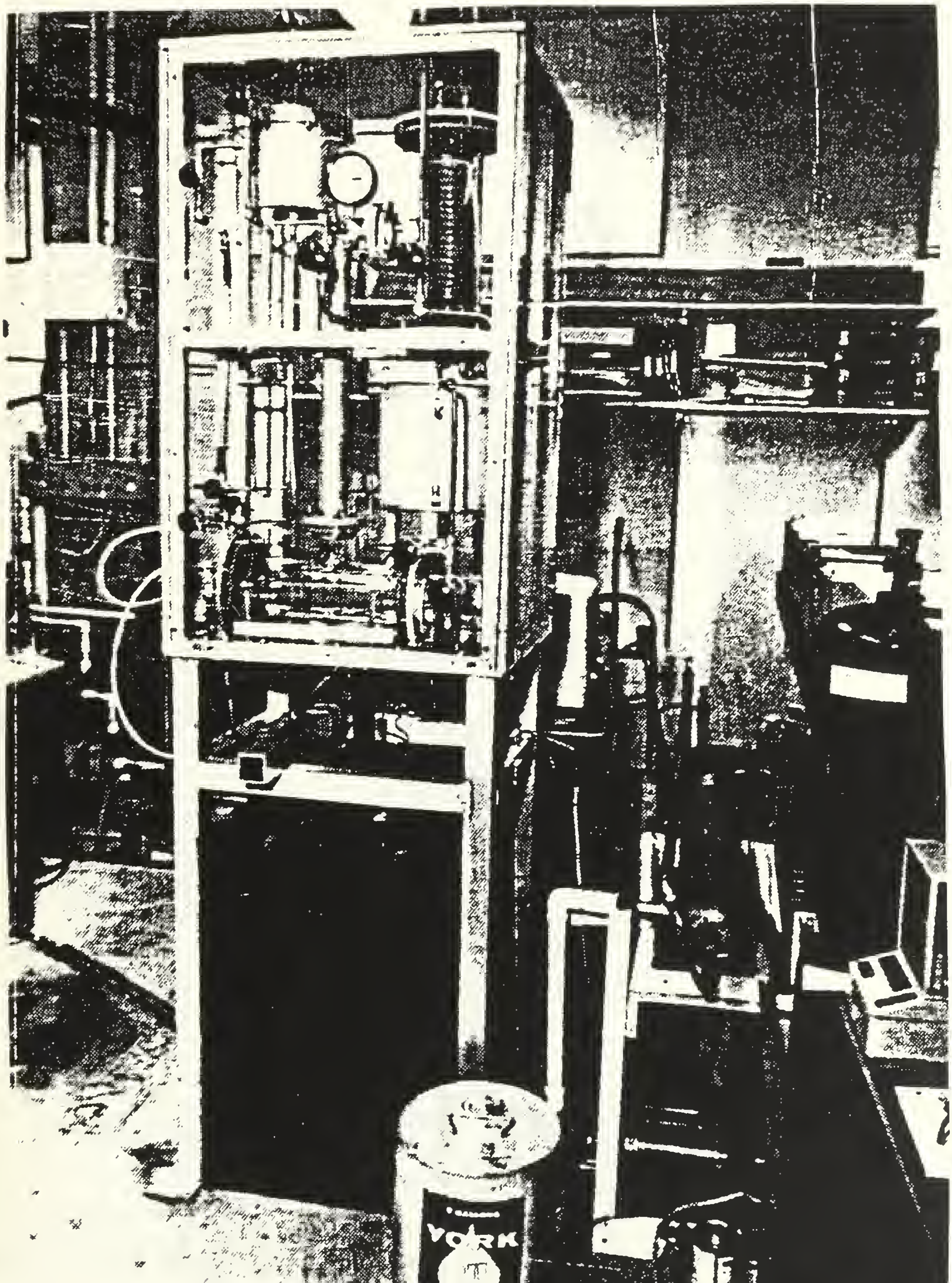
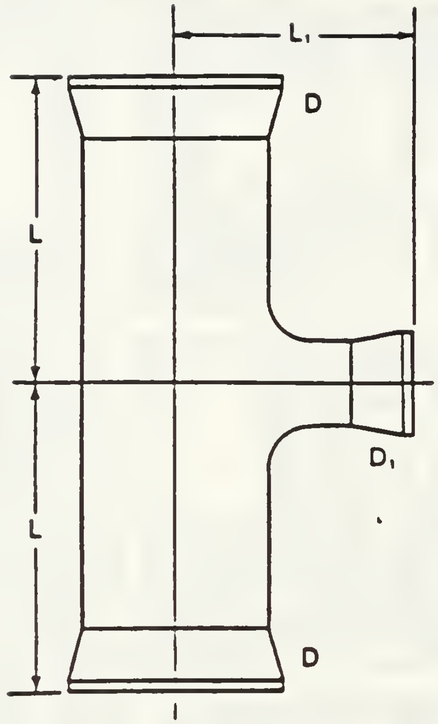
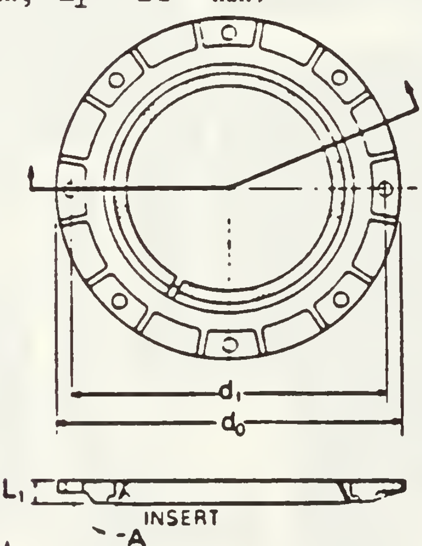


Figure 3.2 Photograph of Experimental Apparatus



a) Corning Pyrex Glass Evaporator ($D \times D_1$ = 402x51 mm, L = 178 mm, L_1 = 127 mm)



b) Cast Iron Flange and Gasket (d_1 = 190mm, d_0 = 210mm, L_1 = 14mm, A = 21°)

Figure 3.3 Schematic of the Pyrex Glass Evaporator

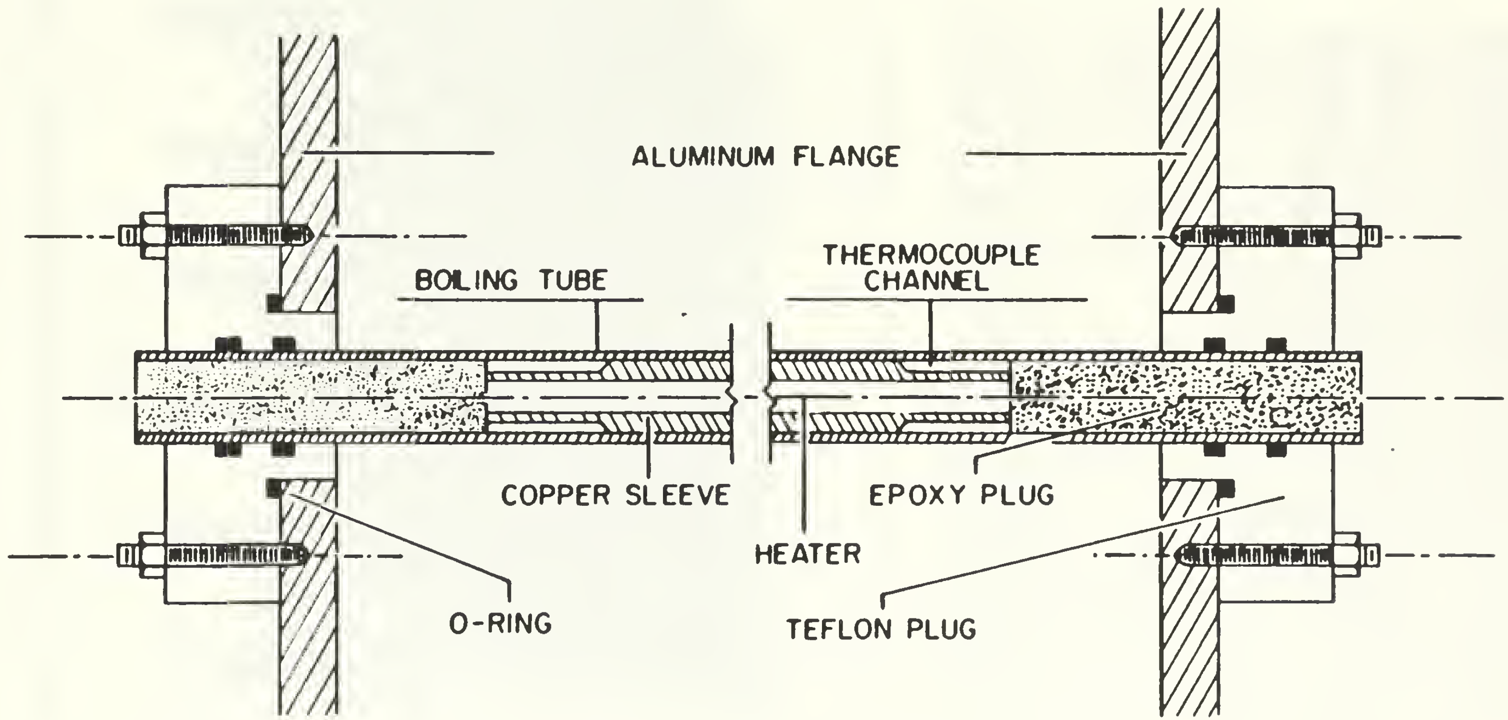
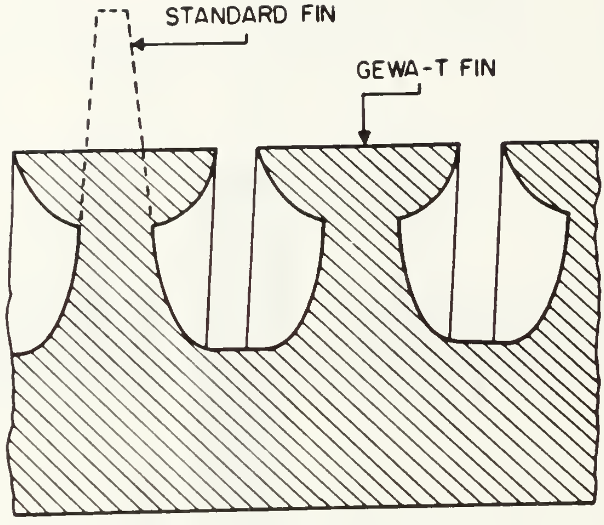
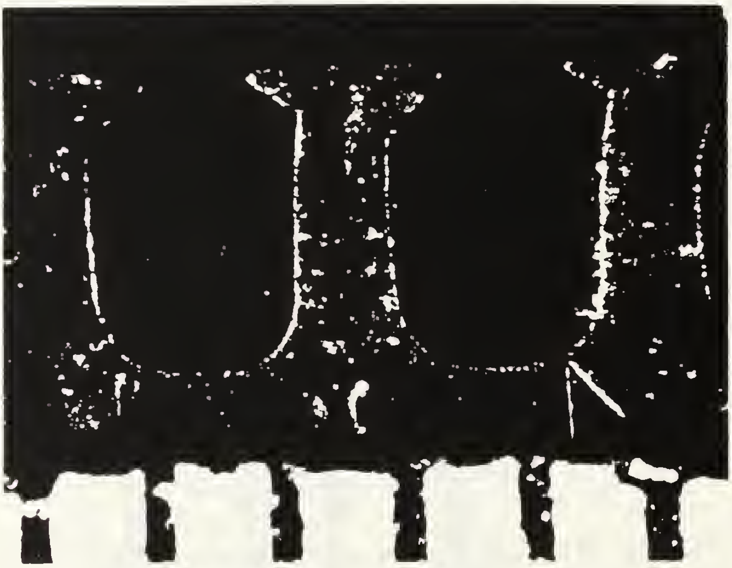


Figure 3.4 Schematic of the Boiling Test Tube

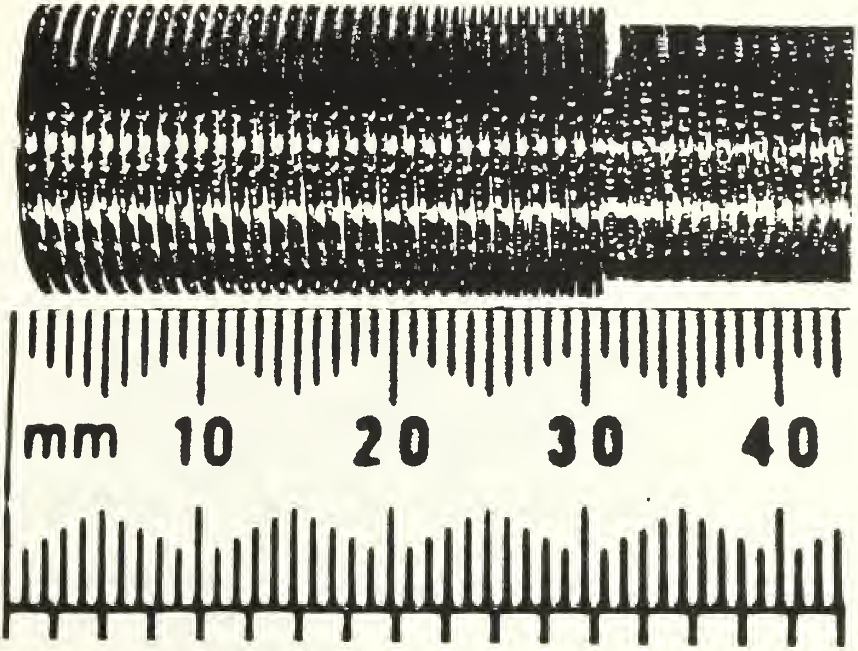


(a) Standard fin (GEWA-K) and GEWA-T fin



(b) GEWA-T fin

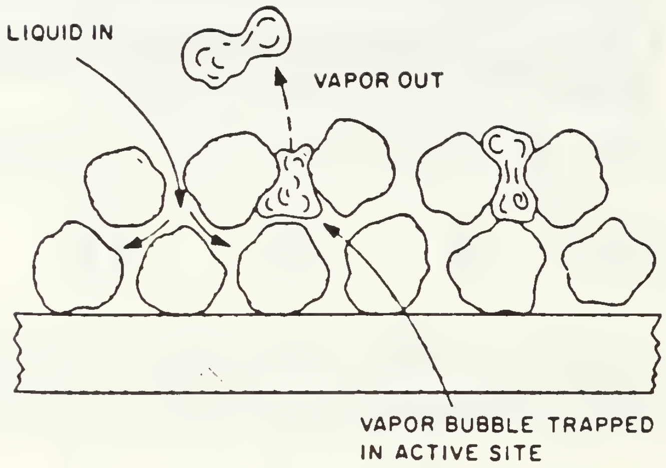
Figure 3.5 Schematic and Photograph of Fins



(a) GEWA-YX tube

(b) GEWA-YX fin

Figure 3.6 Photographs of GEWA-YX Tube and Fin



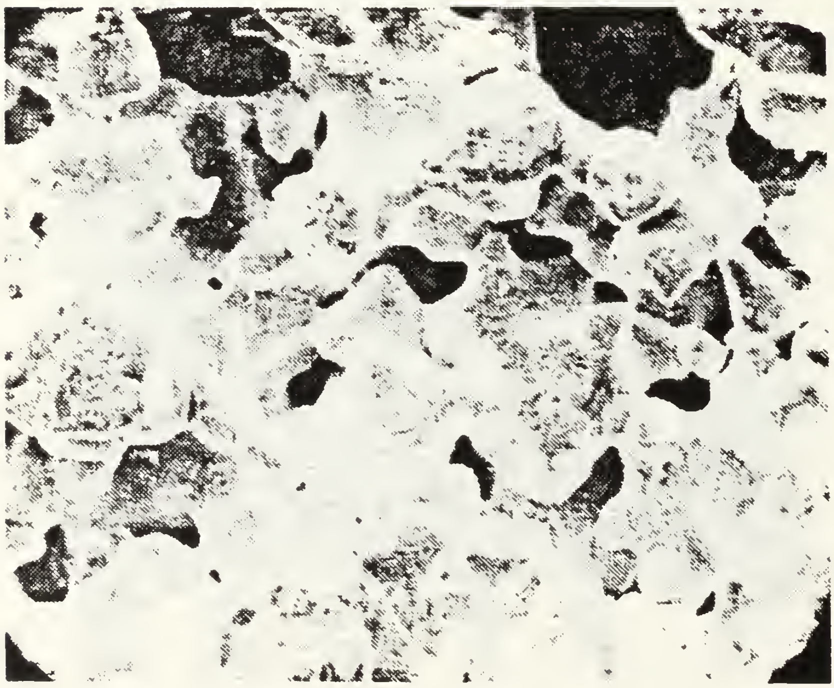
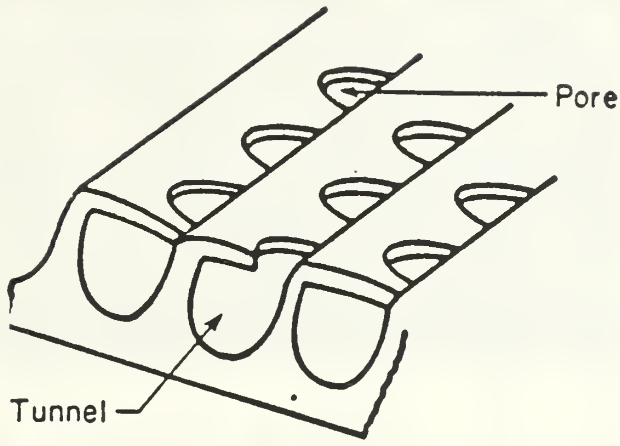


Figure 3.7 Schematic and Photograph of High Flux Surface



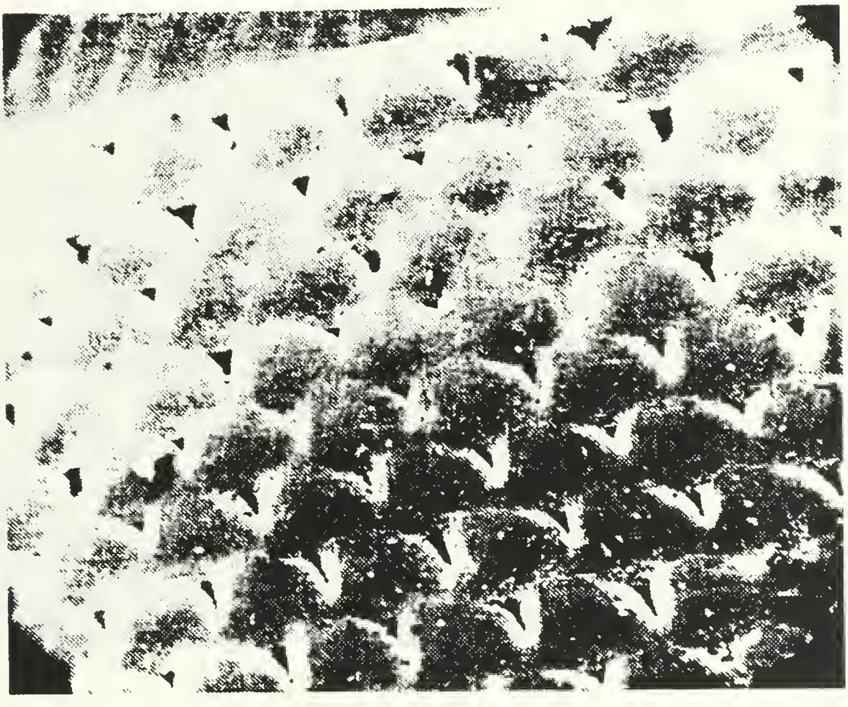
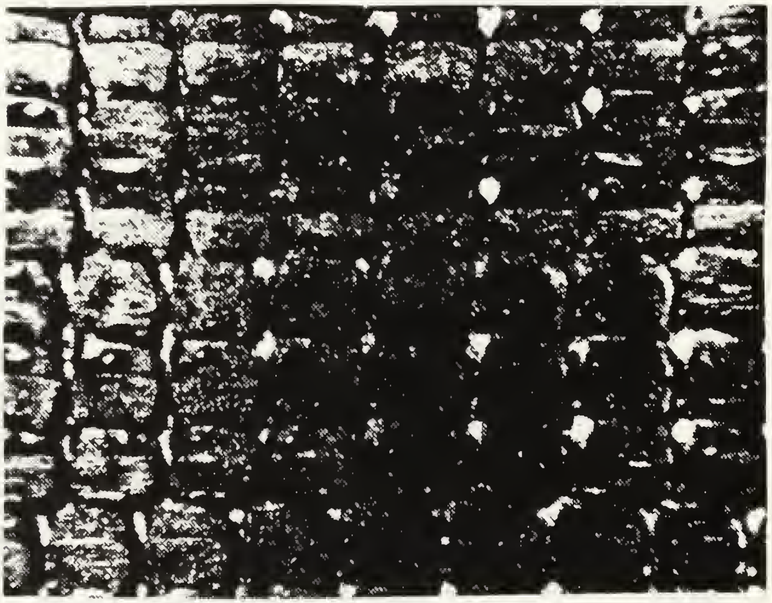


Figure 3.8 Schematic and Photograph of Thermoexcel-HE Surface

(a) Thermoexcel-E



(b) Turbo-B

Figure 3.9 Photographs of Re-Entrant Cavity Surfaces

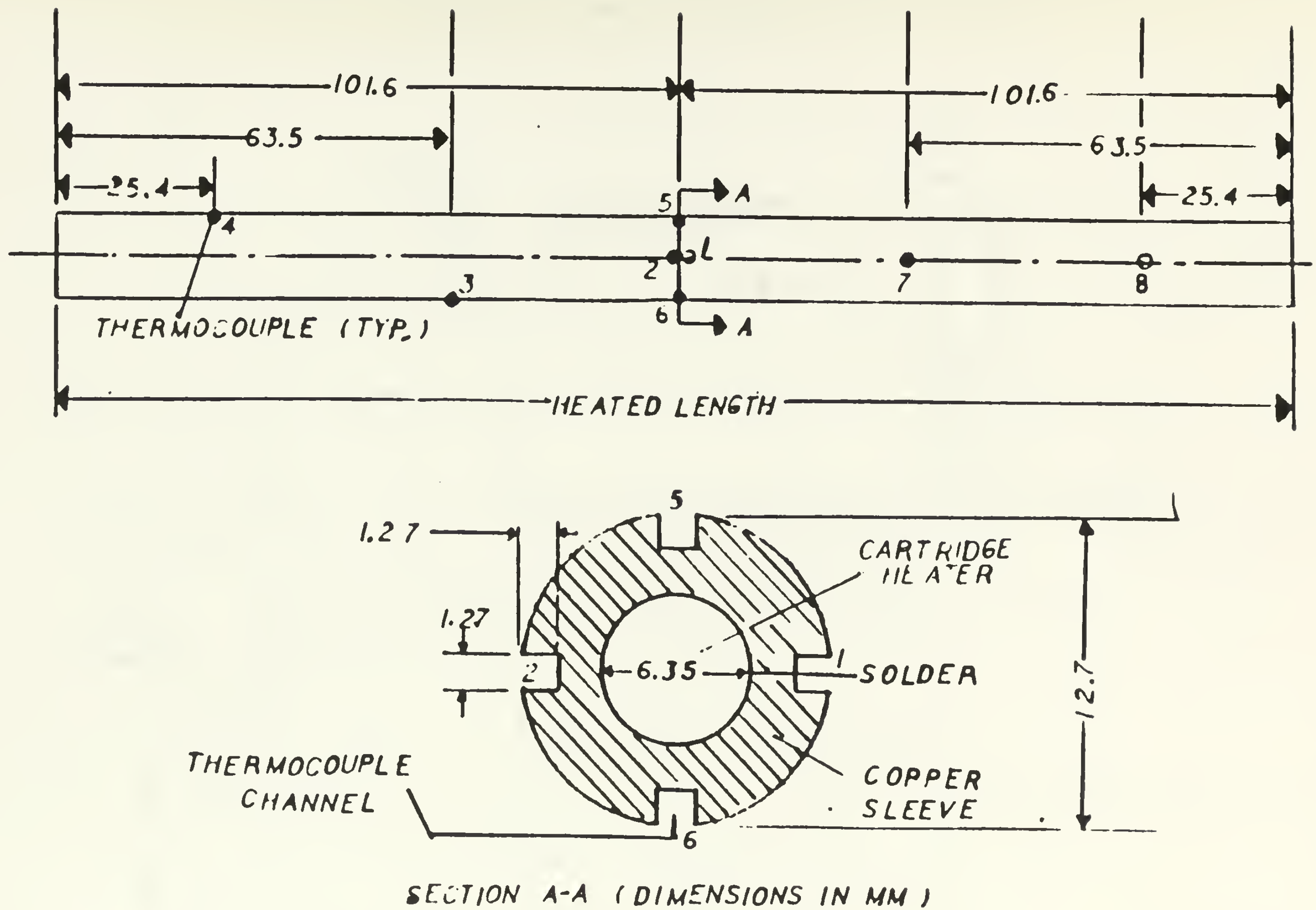


Figure 3.10 Positions of the Thermocouples

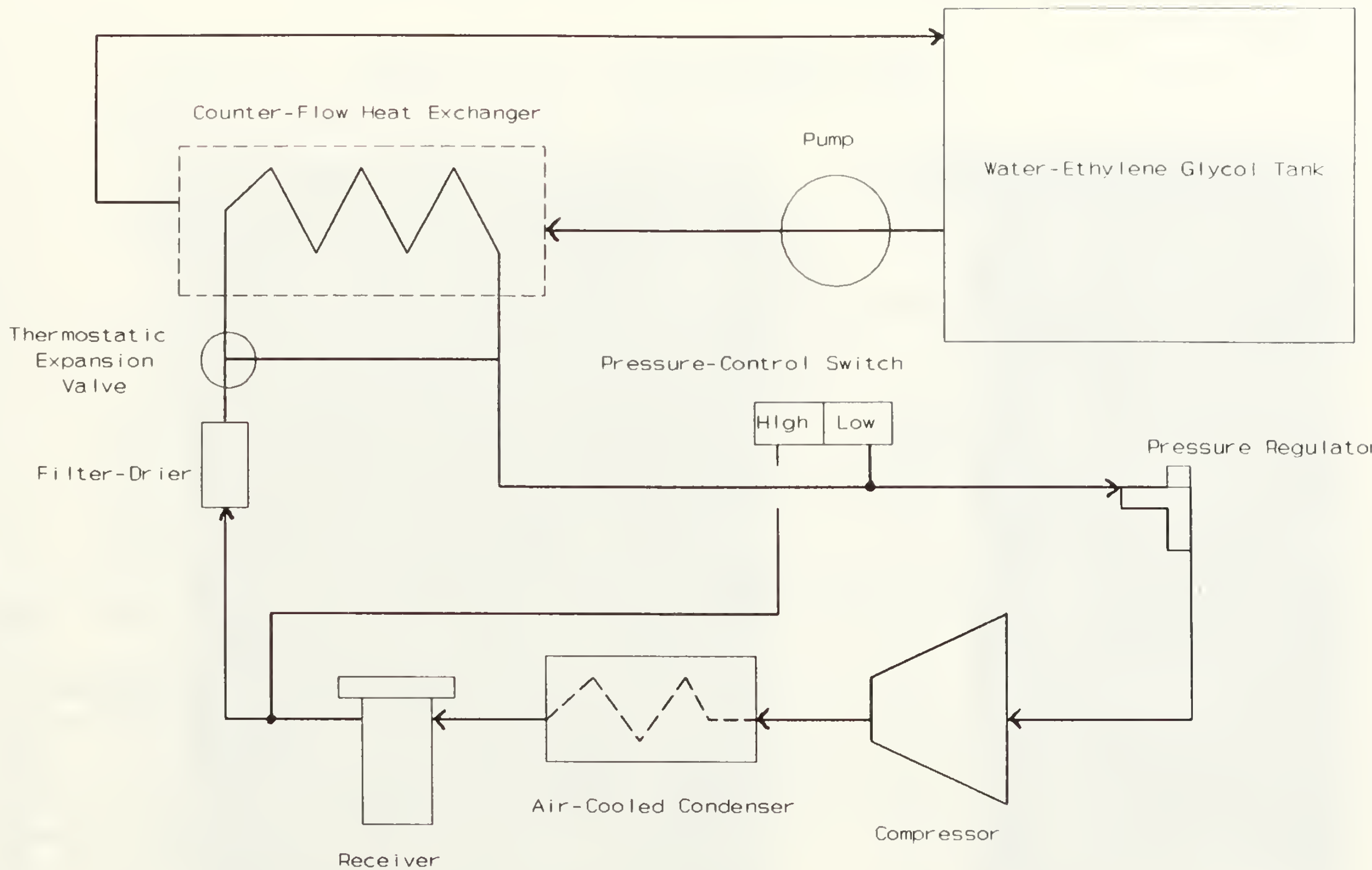


Figure 3 11 Schematic of R-502 Refrigeration System

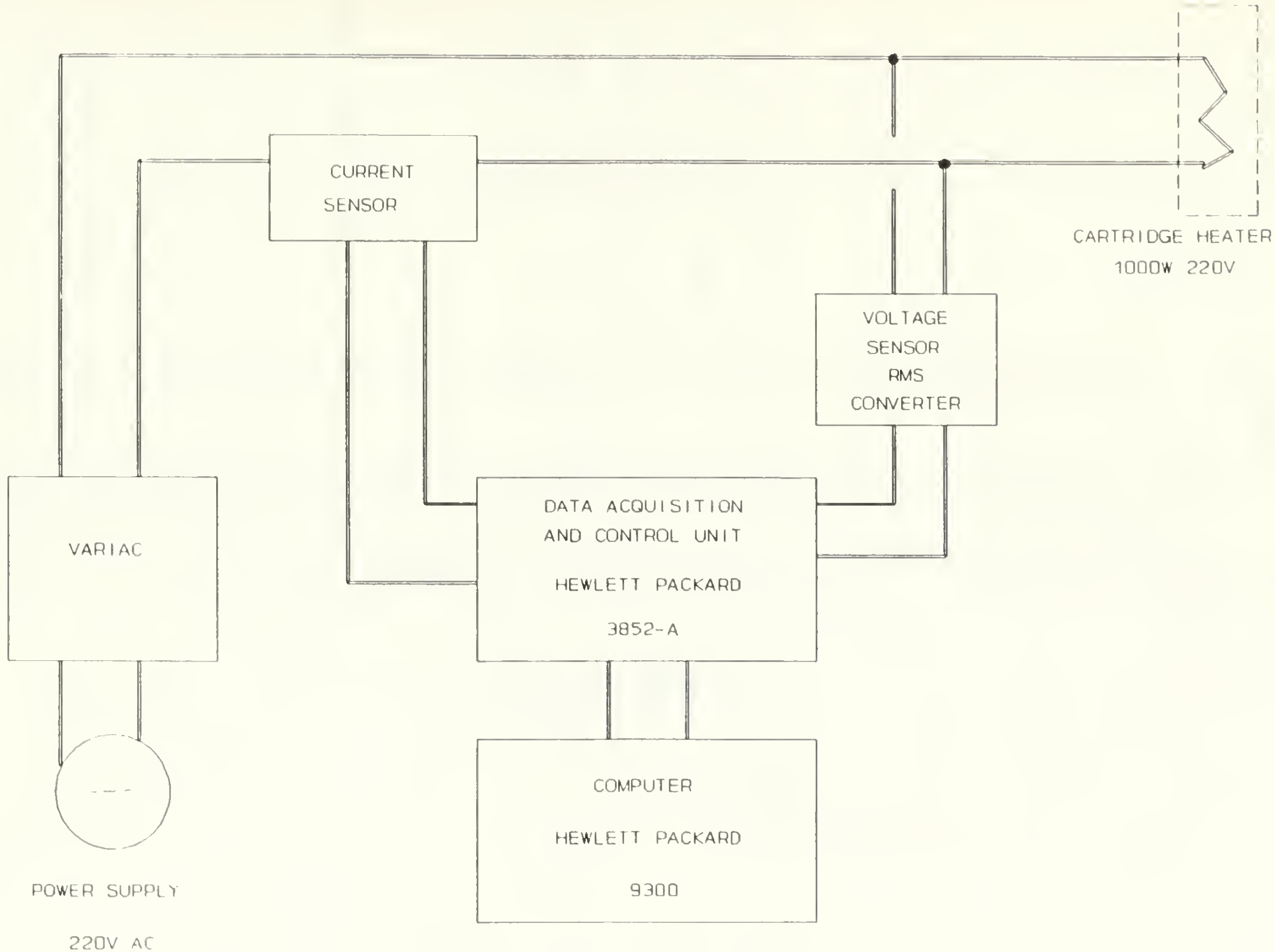


Figure 3.12. Schematic of the Power Measurement

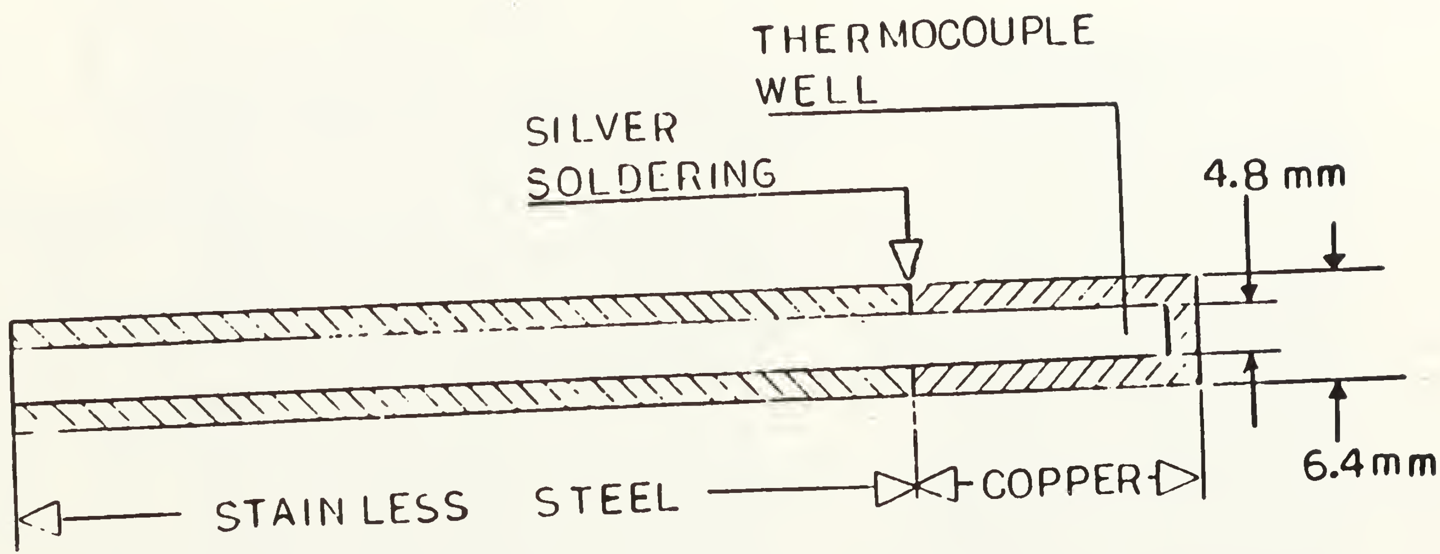


Figure 3.13 Sketch of a Thermocouple Well

IV. DATA ACQUISITION AND REDUCTION

A. DATA ACQUISITION AND STORAGE

A Hewlett-Packard 3852A automatic data acquisition unit was used to read temperatures from the thermocouples and to read current and voltage values of the cartridge heater from the AC current sensor and the AC-DC true RMS converter. A Hewlett-Packard 9000 Series computer was used to control the measurements done by the 3852A, analyze the collected data and store it.

The iterative data collection/reduction program DRP8 was loaded and run. Information was entered through the keyboard to prompt the data acquisition unit when to take data. Channel assignments are listed in Table I. The raw data was processed and transferred to a file on the computer's hard drive. A printout of the data reduction was also provided.

B. DATA REDUCTION

Following data acquisition for each data point, results were computed according to the stepwise procedure outlined in the next section, and then printed out using a Hewlett-Packard Inkjet printer. Graphs were plotted using commercial software.

C. STEPWISE DATA-COLLECTION AND SOLUTION PROCEDURE

1. Input name of user-specified file to be stored on computer hard drive.

2. Select tube type (all dimensions of the boiling test tube are included).

3. Input desired heat flux (W/m^2) and saturation temperature (°C) of the boiling liquid.

4. Set desired heat flux by adjusting VARIAC rheostat.

5. Set saturation temperature by adjusting flow of coolant through condenser coils with control valve VC.

6. Once saturation temperature is achieved, wait for steady-state conditions (at least 5 minutes) prior to taking data readings.

7. Prompt data acquisition unit to scan all channels listed in Table I (thermocouples, AC current sensor and AC-DC true RMS voltage converter). All channel readings are made in volts and stored in user specified file.

8. Convert these voltage readings to corresponding units (temperature in °C, current in amperes, voltage in volts). Karasabun [Ref. 15] describes in detail conversion equation for temperature. See Appendix B-Data Acquisition Apparatus Calibration for details of current and voltage conversion.

9. Compute the heat-transfer rate from the cartridge heater. See Appendix D-Sample Calculations.

10. Compute the average wall temperature of the boiling tube and calculate the wall superheat of the current data set. See Appendix D-Sample Calculations.

11. Compute the physical properties of R-114 using given correlations at film temperature. See Appendix D-Sample Calculations.

12. Compute the natural-convection heat-transfer coefficient of R-114 from the smooth non-boiling ends of the test tube. See Appendix D-Sample Calculations.

13. Compute heat losses from the non-boiling ends of the boiling tube. See Appendix D-Sample Calculations.

14. Calculate the heat flux from tube to the refrigerant. See Appendix D-Sample Calculations.

15. Calculate the heat transfer coefficient of the R-114 from the boiling tube. See Appendix D-Sample Calculations.

16. Store the heat flux versus wall superheat values for each data set in user-specified file.

17. Use commercial software, Harvard Graphics, to plot data.

TABLE I. HP 3497A CHANNEL ASSIGNMENTS

Channel	Assignment
500-507	Boiling tube wall temperature
508-509	Boiling liquid temperature
510	Vapor temperature
511	Sump temperature
512	RMS voltage Tube heaters
513	Tube heater current sensor
514	Auxiliary heater current sensor

V. EXPERIMENTAL PROCEDURE

A. PREPARATION

1. Vacuum test of the Apparatus

Upon changing the tube and reassembling the apparatus, the system was evacuated down to approximately 25 in. Hg. by a portable mechanical vacuum pump through valves V11 and V8. The apparatus was allowed to stand for 30 minutes under vacuum to observe any possible leaks. During this period, thermocouples were connected to the data acquisition system, the electrical integrity of the tube heater was checked and the tube heater connected to the variac panel. If a leak was detected (i.e. an observed rise in pressure), a pressure test was conducted to isolate the source. (See V.A.2.)

2. Pressure Test of the Apparatus

In order to detect sources of leaks, the apparatus was pressurized with air up to 15 psi gage and a soap/water bubble test was carried out upon suspect joints. All detected leaks were successfully and systematically fixed.

3. Charging the Apparatus with R-114

Upon completing the pressure tests (if any), the evaporator of the apparatus was filled with R-114 liquid up to a marked position (20 mm above the top of the boiling tube) using the following procedure.

1. Valve V7 was opened to allow the pressures within the reservoir and the evacuated apparatus to equalize. It was noted that the liquid R-114 within the reservoir boiled since the equilibrium pressure was less than the R-114 vapor pressure at room temperature.

2. Valve V6 was opened to allow the liquid R-114 to drain into the evaporator by gravity.

3. At the designated evaporator level, valves V6 and V7 were closed to isolate the reservoir.

4. Degassing and Data Acquisition Channel Check.

1. With the condenser operating, the boiling tube was run at a high flux of about 100 kW/m^2 for ten minutes in order to de-gas both the tube surface and refrigerant. Care was taken not to exceed a pressure of 15 psi gage (well below manufacturer recommendation) within the apparatus.

2. Any noncondensible gases present collected in the top of the condenser. These were then removed using the vacuum pump through valves, V8 and V11.

3. The program, SETUP8, was run to check output on all thermocouple channels as well as power output. If an erroneous reading was detected, then appropriate action was taken. In the case of a faulty boiling tube wall thermocouple, the faulty thermocouple was tagged for future exclusion in data acquisition procedure. (Each thermocouple had X thermocouples embedded in its tube wall and the loss of one made no difference to the average wall temperature).

4. The apparatus was shut down and the boiling tube allowed to soak in the refrigerant overnight. This allowed for the surface to become wetted.

B. NORMAL OPERATION

The following procedure was followed to obtain the heat-transfer coefficient of pure R-114 and R-114/oil mixtures from the boiling tube being tested:

1. The R-502 refrigeration unit was operated 1-2 hours in advance in order to reduce the temperature of the water-ethylene glycol sump to a minimum of -8 °C.

2. The data acquisition/control unit, computer and variac panel were switched on.

3. The computer program Setup8 was loaded and run:
   a. All the data acquisition channels were rechecked.
   b. A power output of approximately 5W was input to the boiling tube. This has been measured to produce a heat flux of 500 to 600 W/m^2 in all tubes tested which facilitated reaching the first data point on the increasing flux run.
   c. The temperature of the refrigerant was slowly reduced down to 2.2 °C by circulating a small amount of coolant through the condenser, regulated by control valve, VC. This reduction was monitored to coincide with the reduction in sump temperature.

4. The iterative computer program DRP8 was loaded and run.

5. Two data runs were made: an increasing heat flux run and a decreasing heat flux run wherein the heat flux was incrementally increased or decreased. Ten different heat fluxes (0.6, 1, 2, 3.5, 6, 10, 20, 35, 60, and 100 kW/m^2) were selected for each increasing or decreasing heat flux data run.

6. The desired heat flux and saturation temperature were input to the program as reference points for each data point.

7. The variac was adjusted to set the actual heat flux which was continuously compared to the desired heat flux by the program until they agreed within 2 percent.

8. The control valve VC was adjusted to regulate the flow of cooling liquid through the condenser to maintain nearly constant saturation temperature at a given heat flux. Desired versus actual saturation temperatures were monitored continuously by the program until they agreed ± 0.1 °C.

9. For each data point, conditions in the evaporator were allowed to stabilize for at least 5 minutes prior to measuring the raw data. The following raw data were measured and stored in a user specified file: boiling tube wall thermocouple readings, liquid bulk

thermocouple readings, vapor thermocouple readings, sump thermocouple readings, current sensor readings, and voltage sensor readings.

10. Two data points were taken at a given heat flux and saturation temperature to comprise a data set. The following processed data were recorded as a printout: wall temperatures of the boiling section, liquid bulk temperatures, vapor temperature, sump temperature, wall superheat, heat transfer coefficient of the R-114/R-114-oil mixture and the actual heat flux.

11. For each data set, the above procedure beginning with step 5 was repeated.

12. Table II provides a listing of all data runs.

TABLE II. LISTING OF DATA RUNS

Data Run #	**Data File**	**Tube**	**Heat Flux**	**Oil (%)**	**Purpose**
1	DATA630I5	HF	I	0	CAL
2	DATA630D5	HF	D	0	CAL
3	DATA702I5	HF	I	0	CAL
4	DATA702D5	HF	D	0	CAL
5	DATA0705I5	HF	I	0	CAL\DATA
6	DATA0705D5	HF	D	0	CAL\DATA
7	DATA0709I4	SM	I	0	DATA
8	DATA0709D4	SM	D	0	DATA
9	DAT0710I6	GK-40	I	0	DATA
10	DAT0710D6	GK-40	D	0	DATA
11	DAT0711I7	GK-26	I	0	DATA
12	DAT0711D7	GK-26	D	0	DATA
13	DAT0715I8	GT-19	I	0	DATA
14	DAT0715D8	GT-19	D	0	DATA
15	DAT0716I9	GT-26	I	0	DATA

Data Run #	Data File	Tube	Heat Flux	Oil (%)	Purpose
16	DAT0716D9	GT-26	D	3	DATA
17	DAT0717I11	T-HE	I	3	DATA\DG
18	DAT0717D11	T-HE	D	0	DATA
19	DAT0722I12	TB	I	0	DATA
20	DAT0722D12	TB	D	0	DATA
21	DAT0723I09	GY-26	I	0	DATA
22	DAT0723D09	GY-26	D	0	DATA
23	DAT0724I11	T-HE	I	0	DATA\DG
24	DAT0724D11	T-HE	D	0	DATA\REP
25	DAT0803I4	SM	I	0	DATA\REP
26	DAT0803D4	SM	D	3	DATA\REP
27	DAT0804I4	SM	I	[illegible]	DATA
28	DAT0804D4	SM	D	[illegible]	DATA
29	DAT0805I4	SM	I	10	DATA
30	DAT0805D4	SM	D	10	DATA
31	DAT0806I7	GK-26	I	0	DATA\REP
32	DAT0806D7	GK-26	D	0	DATA\REP
33	DAT0807I7	GK-26	I	3	DATA
34	DAT0807D7	GK-26	D	[illegible]	DATA
35	DAT0808I7	GK-26	I	10	DATA
36	DAT0808D7	GK-26	D	10	DATA
37	DAT0809I6	GK-40	I	3	DATA\REP
38	DAT0810D6	GK-40	D	0	DATA\REP
39	DAT0810I6	GK-40	I	3	DATA
40	DAT0810D6	GK-40	D	3	DATA
41	DAT0812I6	GK-40	I	10	DATA
42	DAT0812D6	GK-40	D	10	DATA
43	DAT0815I8	GT-19	I	0	DATA\REP

Data Run #	Data File	Tube	Heat Flux	Oil (%)	Purpose
44	DAT0815D8	GT-19	D	3	DATA\REP
45	DAT0816I8	GT-29	I	3	DATA
46	DAT0816D8	GT-19	D	3	DATA
48	DAT0820D8	GT-19	I	10	DATA
48	DAT0820D8	GT-19	D	10	DATA
49	DAT0821I9	GT-26	I	3	DATA
50	DAT0821D9	GT-26	D	3	DATA
51	DAT0822I9	GT-26	I	10	DATA
52	DAT0822D9	GT-26	D	10	DATA
53	DAT0823I10	T-E	I	3	DATA
50	DAT0823D10	T-E	D	3	DATA
55	DAT0824D10	T-E	I	10	DATA
56	DAT0824D10	T-E	D	10	DATA
57	DAT0825D9	GY-26	I	3	DATA
56	DAT0825D9	GY-26	D	3	DATA
56	DAT0826I9	GY-26	I	10	DATA
60	DAT0828D5	GY-26	D	10	DATA
61	DAT0828I5	HF	I	3	DATA
62	DAT0827D5	HF	D	3	DATA
63	DAT0828I5	HF	I	10	DATA
64	DAT0828D5	HF	D	10	DATA
68	DAT0829D12	TB	I	3	DATA
66	DAT0829D12	TB	D	3	DATA
68	DAT0830I12	TB	I	10	DATA
68	DAT0830D12	TB	D	10	DATA
69	DAT0831I11	T-HE	I	3	DATA
70	DAT0831D11	T-HE	D	3	DATA
71	DAT0901I11	T-HE	I	10	DATA

Data Run #	Data File	Tube	Heat Flux	Oil (%)	Purpose
72	DAT0901D11	T-HE	D	10	DATA
73	DAT0906I10	T-E	I	0	DATA
74	DAT0906D10	T-E	D	0	DATA

SM = Smooth GK-26 = GEWA-K 26 fpi GK-40 = GEWA-K 40 fpi
HF = High Flux GT-19 = GEWA-T 19 fpi GT-26 = GEWA-T 26 fpi
TB = Turbo-B GY-26 = GEWA-YX 26 fpi T-E = Thermoexcel-E
T-HE = Thermoexcel-HE
I = Increasing Flux D = Decreasing Flux

CAL = CALIBRATION DATA DATA = BASELINE DATA
REP = REPEATABILITY DATA DG = DEGASSING DATA

VI. RESULTS AND DISCUSSION

A. REPRODUCIBILITY

To test the reproducibility of the experimental data, 9 data runs were repeated on different days. All data runs were conducted at a saturation temperature of 2.2 °C. Figure 6.1 shows a comparison of two pairs of runs, 13, 14, and 43, 44 for increasing and decreasing heat flux. It can be seen that there is excellent agreement between both the increasing and decreasing heat flux runs.

B. COMPARISON OF DATA WITH PREDICTION

To check the general validity of the data obtained, four well-known correlations, two for natural convection and two for nucleate pool boiling, were plotted and compared with the smooth tube data for pure R-114. The two natural convection correlations used were Churchill and Chu [Ref. 1] and a more recent update Churchill and Usagi [Ref. 2]. The two nucleate pool boiling correlations used were: Rohsenow [Ref. 1] and Stephan-Abdelsalam [Ref. 3]. One of the first correlations developed, the Rohsenow correlation is based upon the physics of pool boiling heat transfer. It applies only for clean surfaces and when used to estimate heat flux, errors can amount to ± 100%. The Stephan-Abdelsalam correlation for refrigerants was developed from application of regression

analysis to a large amount of existing data. Application to a large number of pure substances of widely differing thermal properties is remarkably simple. Figure 6.2 shows the plotted data and correlations. It can be seen from the plot that there is excellent agreement for natural convection and not bad agreement in the nucleate boiling region. The slightly worse agreement for nucleate boiling can be attributed to the more complex mechanisms at work in this region.

C. EFFECTS OF DEGASSING

Early experiments (Runs 1-6) conducted with the High Flux tube pointed out the significant effect of degassing both the tube surface and refrigerant. It was observed that tubes that were not vigorously boiled after placement into the apparatus and not allowed to settle overnight, tended to nucleate at very low heat fluxes the following day when conducting an increasing heat flux run. Similar effects were observed if the apparatus was allowed to stand undisturbed for several days. The most extreme effects were seen for the re-entrant cavity tubes. Figure 6.3 shows the change in behavior (i.e. for gassed and degassed) for a Thermoexcel-E tube for an increasing heat flux run. For the degassed case, an extreme temperature overshoot was observed, which indicates a large number of nucleation sites were deactivated. Once all nucleation sites were activated, the performance of both cases was identical. It can be surmised that the entrapment of vapor

bubbles in surface cavities as well as the outgassing from the Teflon O-rings of the rig over time, enhanced the nucleation on the tube surfaces. Vigorous boiling removed those gases from both surface and liquid.

D. BOILING PERFORMANCE OF ENHANCED TUBES IN PURE R-114 AND R-114/OIL MIXTURES

The results of the 74 data runs are discussed with references to the figures (Figures 6.1 to 6.80) that are provided at the end of this chapter. Performance of each tube will be presented and discussed as follows:

1. For pure R-114
2. For R-114/oil mixtures (3% and 10% by weight)
3. Comparison of pure R-114 and R-114/oil mixtures for increasing heat flux runs.
4. Comparison of pure R-114 and R-114/oil mixtures for decreasing heat flux runs.
5. Comparison to similar tube types (i.e. finned - as applicable for each R-114/oil mixture for both increasing and decreasing heat flux runs)

1. Boiling Performance of Smooth Tube

Figures 6.4, 6.5 and 6.6 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a smooth copper tube. Figures 6.7 and 6.8 show the comparative performance for the three refrigerant/oil mixtures on increasing and decreasing heat flux respectively. It can be seen that in Figure 6.7 in the natural convection region there is slight degradation with

increases in oil. However, in the nucleate boiling region there is significant degradation with increasing oil concentration. Wanniarachi *et al.* [Ref. 6] reported similar behavior for smooth tubes. This behavior was attributed to two competing effects: (1) the 'choking' of the tube surface by an oil rich layer which develops as the more volatile refrigerant is boiled off; () the diffusion of the miscible oil rich layer back into the bulk fluid. In the natural convection region it can be surmised that the diffusion effect predominates while in the nucleate boiling region the 'choking' effect eventually overwhelms the diffusion. This degradation is seen again in Figure 6.8. It can be seen that in Figure 6.8 that as conditions approach natural convection along the decreasing heat flux curve, the three mixtures perform similarly as nucleation sites die out.

2. Boiling Performance of Finned/Modified Finned Tubes

Figures 6.9, 6.10 and 6.11 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a standard 26 fpi tube, (GEWA-K). At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil and R-114/10% oil was 2.4, 2.9 and 3.2 respectively. Figures 6.12 and 6.13 show the comparative performance of the three refrigerant/oil mixtures on increasing heat flux and decreasing heat flux runs

respectively. On increasing heat flux and decreasing heat flux runs, the finned tube only shows a small degradation in both the natural convection and nucleate boiling regions. The smooth tube only shows small degradation in the natural convection region. Also, at the higher heat fluxes, the R-114/3% oil mixture shows a slightly better performance than the pure R-114 and R-114/10% oil mixture. This phenomenon was observed for all finned tubes, however, the reasons for such behavior are not fully understood; it may be due to bubble 'scouring' between the fins. This small increase in performance at low oil concentrations agrees with results reported by Stephan and Mitrovic [Ref. 15].

Figures 6.14, 6.15 and 6.16 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a GEWA-K 40 fpi tube. Figures 6.17 and 6.18 show the comparative performance of the three refrigerant/oil mixtures on increasing heat flux and decreasing heat flux respectively. Similar behavior to the GEWA-K 26 fpi tube was observed including the improved performance at higher fluxes at low oil concentrations (3%).

Figures 6.19, 6.21, and 6.23 show the comparative performance of the three R-114/oil mixtures boiling from GEWA-K 26 and 40 fpi tubes on increasing heat flux. For all three oil concentrations, the GEWA-K 40 fpi tube outperforms the GEWA-K 26 fpi and smooth tubes consistently in the nucleate boiling region. At a heat flux of 35 kW/m^2 the GEWA-K 40 fpi

and the GEWA-K 26 fpi had heat transfer enhancements of 4.1 and 3.1 respectively over the smooth tube for pure R-114. Similar enhancements were seen at R-114/3% oil and R-114/10% oil mixtures. See Table III at end of this chapter. In the natural convection region, the results were mixed. Neither tube predominated consistently for pure R-114 and R-114/oil mixtures. Figures 6.20, 6.22 and 6.24 show similar comparisons on decreasing heat flux. It can be seen that the GEWA-K 40 fpi performs best in all three cases except at very low fluxes where results were less certain. However, the calculation for the heat flux did not take into account the actual increases in surface area for the finned tubes over the smooth tube. A fin root diameter was used to calculate surface area. The actual area increase is of the same magnitude as the heat transfer enhancements seen, indicating that both smooth and finned tubes give similar heat transfer performance. To demonstrate this, Figure 6.9, the GEWA-K 26 fpi tube in pure R-114, is replotted in Figure 6.81 using the actual fin surface area. The ratio of actual fin surface area to root diameter area was a factor of 4. Actual surface heat flux was calculated by dividing the root diameter surface heat flux by four. It can be seen in Figure 6.81 that in the natural convection region the GEWA-K 26 fpi tube performs comparably to the smooth tube. However, in the mixed boiling and nucleate boiling regions the GEWA-K 26 fpi tube shows an enhanced performance over the smooth tube up to three, which indicates

there are other mechanisms involved besides increased surface area.

Figures 6.25, 6.26 and 6.27 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a modified fin tube, GEWA-T 19 fpi. At a heat flux of 35 kW/m^2, the heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 3.1, 4.3 and 5.2 respectively. Figures 6.28 and 6.29 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. Similar to the GEWA-K type tube, only a slight degradation is observed in both the natural convection and nucleate boiling regions. Again at higher heat fluxes, the R-114/3% oil mixture performed best.

Figures 6.30, 6.31 and 6.32 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a GEWA-T 26 fpi tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 3.7, 4.6 and 4.8 respectively. Figures 6.33 and 6.34 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing oil mixtures respectively. It can be seen that at higher heat fluxes, the R-114/3% oil mixture performed best and there was significant degradation in performance for the R-114/10% oil

mixture compared to the smooth tube. At lower heat fluxes, the pure R-114 outperformed the refrigerant/oil mixtures. It can be surmised that the 'choking' effect predominates for the refrigerant/oil mixtures.

Figures 6.35, 6.37 and 6.39 show the comparative heat transfer performance of each refrigerant/oil mixture boiling from the GEWA-T 19 and 26 fpi tubes for increasing heat fluxes. Figures 6.36, 6.38 and 6.40 show similar comparisons for decreasing heat fluxes. It can be seen that in the nucleate boiling region at the higher heat fluxes that the GEWA-T 26 fpi tube performed best. At the lower heat fluxes, in the natural convection region for an increasing heat flux run the tubes performed equally. For a decreasing heat flux run, the GEWA-T 19 fpi performed best. Recalling the channel structure of the GEWA-T tube suggests more complex phenomena than simple increase in surface area. Indeed Marto *et al.* [Ref. 16] have found that the gap width with GEWA-T tubes has a significant effect on boiling performance. Down to some limiting value, decreasing the gap width generally increases heat transfer coefficient. The enhancement can be attributed to strong interaction between heat transfer and hydrodynamic effects within GEWA-T channels.

Figures 6.41, 6.42 and 6.43 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from another modified fin tube, GEWA-YX 26 fpi. At a heat flux of 35 kW/m^2, heat

transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 3.4, 4.3 and 4.4 respectively. Figures 6,44 and 6.45 show comparative performance for the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. It can be seen that in the natural convection region slight degradation in performance occurs. At the higher fluxes in the nucleate boiling region, the R-114/3% oil mixture performed best as seen with other types of finned tubes.

Figures 6.46, 6.48 and 6.50 show the comparative performance for each refrigerant/oil mixture boiling from the GEWA-K, GEWA-T and GEWA-YX 26 fpi tubes for increasing heat fluxes. Figures 6.47, 6.49 and 6.51 show similar comparisons for decreasing heat fluxes. Both the modified finned tubes, GEWA-T and GEWA-YX, show marked increases in performance over the standard finned tube, GEWA-K, in the nucleate boiling region. Results were not so clear however in the natural convection region, possibly due to variation in surface area.

3. Boiling Performance of High Flux Tube

Figures 6.52, 6.53 and 6.54 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the High Flux tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 6.4, 6.2 and 3.8. The High Flux tube

displays a much larger relative temperature overshoot compared to the smooth tube and its point of incipience occurs at a much lower heat flux. Accuracy of the data was greatest at high heat flux and large superheat values (± 3.8%) and most uncertain at low heat flux and small superheat values (± 17.15%). See Uncertainty Analysis-Appendix E. It can be seen that at higher heat fluxes that the High Flux tube in the R-114/10 oil mixture performed almost equally to the smooth tube. At a heat flux of 100 kW/m^2 the heat transfer enhancement compared to the smooth tube was 1.1. Wanniarachchi *et al.* [Ref. 7] reported similar results. The marked decrease in boiling performance was attributed to the creation of an oil-rich layer within the boiling pores. The superior boiling performance for R-114/10% oil mixture compared to the smooth tube is completely recovered when the heat flux is decreased. It can be seen that in the natural convection region the performance of the High Flux tube is comparable at all oil concentrations to the smooth tube which indicates there is no effect of either tube type or oil concentration in this region. Figures 6.55 and 6.56 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. The extreme rate of degradation of performance of the High Flux surface at 10% oil concentration with increasing heat flux is clearly seen as well as its complete recovery as the heat flux is decreased.

4. Boiling Performance of the Thermoexcel Tubes

Figures 6.57, 6.58 and 6.59 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the Thermoexcel-E Tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 5.7, 5.3 and 5.2 respectively. Figures 6.60 and 6.61 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. As seen with the High Flux tube, the Thermoexcel-E tube performed equally to the smooth tube in the natural convection region for all refrigerant/oil mixtures.

Figures 6.62, 6.63 and 6.64 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the Thermoexcel-HE tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 4.8, 5.1 and 4.8. Similar performance to the Thermoexcel-E tube was observed. Figures 6.65 and 6.66 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat flux respectively. At a higher heat flux of 100 kW/m^2 the heat transfer enhancements compared to the smooth tube for the R-114/3% oil mixture and R-114/10% oil mixture was reduced to 2.2 and 1.9.

Figures 6.67, 6.69 and 6.71 show the comparative performance of each refrigerant/oil mixture boiling from both the Thermoexcel-E and HE tubes for increasing heat fluxes. Figures 6.68, 6.70 and 6.72 show similar comparisons on decreasing heat fluxes. As discussed earlier both tubes showed improved performance over the smooth tube in the nucleate boiling region. It can be seen that the Thermoexcel-HE tube performed marginally better than the Thermoexcel-E at high heat fluxes. In the natural-convection region both tubes performed comparably to the smooth tube. Wanniarachchi et al [Ref. 8] reported similar behavior for Thermoexcel-E and Thermoexcel-HE tubes. It can be surmised that in the natural convection region the small re-entrant cavities of both tubes do not increase the total boiling surface area like fins. The Thermoexcel-E and HE tubes 'appear' smooth and would be expected to perform comparably to the smooth tube which was indeed seen.

5. Boiling Performance of the Turbo-B Tube

Figures 6.73, 6.74 and 6.75 show heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the Turbo-B tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/oil mixture and R-114/10% oil mixture was 6.2, 6.7 and 5.6 respectively. As seen with all previous re-entrant tubes tested, comparable

performance with the smooth tube is observed in the natural convection region and marked improved performance over the smooth tube is observed in the nucleate boiling region. Figures 6.76 and 6.77 show the comparative performance of each refrigerant/oil mixtures boiling from the Turbo-B tube on increasing and decreasing heat fluxes respectively. Similar to the other re-entrant cavity surfaces tested, the R-114/10% oil mixture had the greatest rate of degradation for increasing heat flux in the nucleate boiling region.

6. Overall Performance of Smooth and Enhanced Surfaces

Figures 6.78, 6.79 and 6.80 show the comparative performance of 8 of the 10 tube surfaces tested. The other two, Thermoexcel-E and GEWA-T 19 fpi, performed similarly to the Thermoexcel-HE and GEWA-T 26 fpi respectively, and so are not included. Three distinct groups of tubes can be identified based upon boiling heat transfer performance at all oil concentrations. These are: (1) smooth, (2) finned/modified finned and (3) re-entrant cavity. Within the finned/modified finned group, it can be seen that the GEWA-T is the best performer. Its enhanced performance was attributed to its channel geometry. The High Flux tube in R-114/10% oil mixture performed comparably to the smooth tube (heat transfer enhancement was 1.1) at a heat flux of 100 kW/m^2. The severe degradation in performance for the High Flux tube can be attributed to the 'choking' of the porous surface. Table III

shows numerically the enhancement in performance over the smooth tube for all three refrigerant/oil mixtures boiling from each of the tubes for three heat fluxes of 10, 35 and 100 kW/m^2. It can be seen at the moderate heat flux of 35 kW/m^2, the finned/modified finned tubes show enhanced performances of 2.4 to 5.2 over the smooth tube while the re-entrant cavity tubes show enhancements of 3.8 to 6.7 over the smooth tube. The effect of oil concentration is significant at high heat fluxes. At a heat flux of 100 kW/m^2 for pure R-114, the finned and re-entrant cavity tubes show comparable enhancement compared to the smooth tube. For R-114/10% oil mixtures at a heat flux of 100 kW/m^2, the finned tubes performed best.

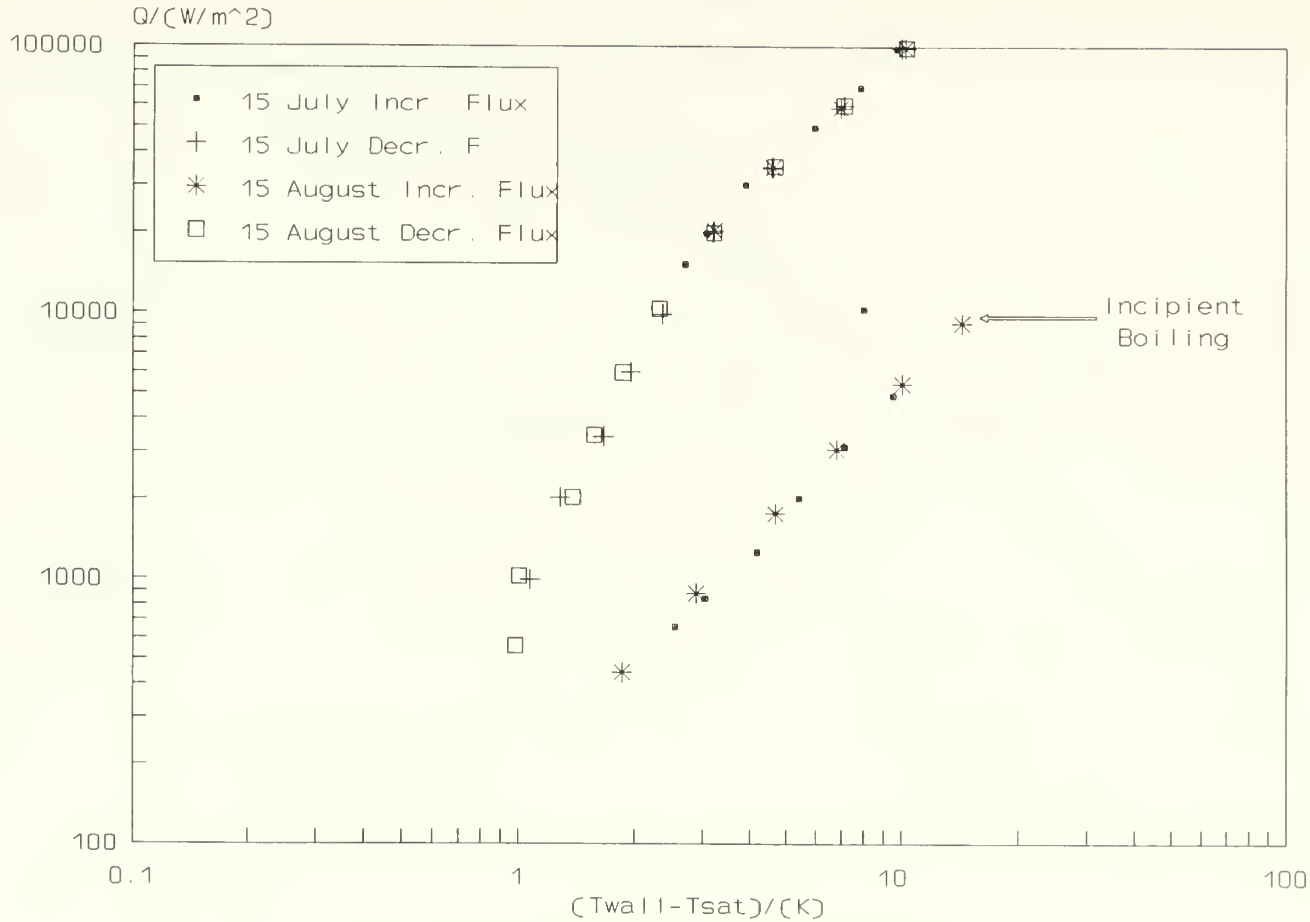


Figure 6.1 Repeatability Comparison For
Pure R-114 Boiling From
GEWA-T 19 fpi Tube

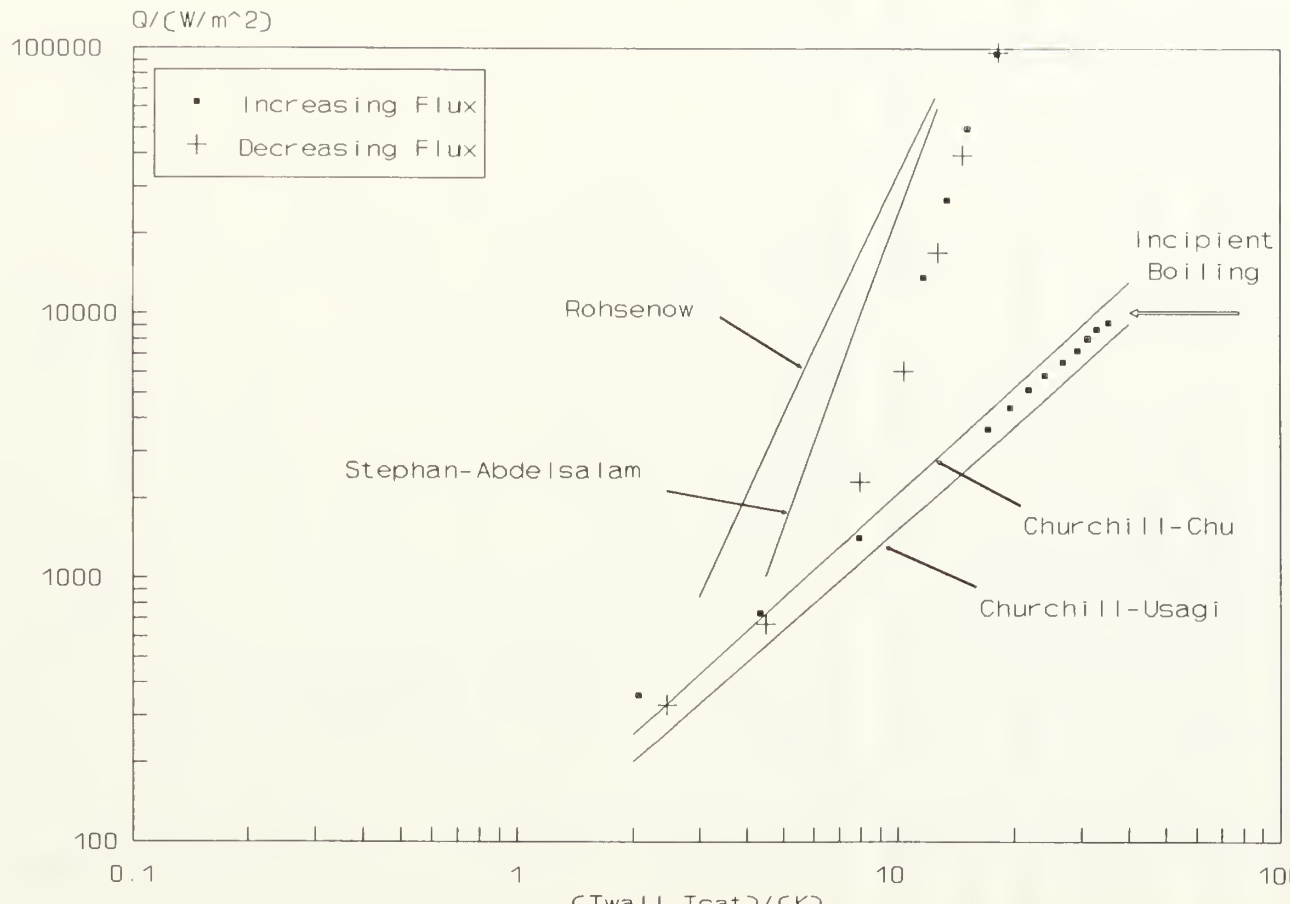


Figure 6.2 Performance Comparison for Pure R-114 Boiling from a Smooth Tube With Known Correlations

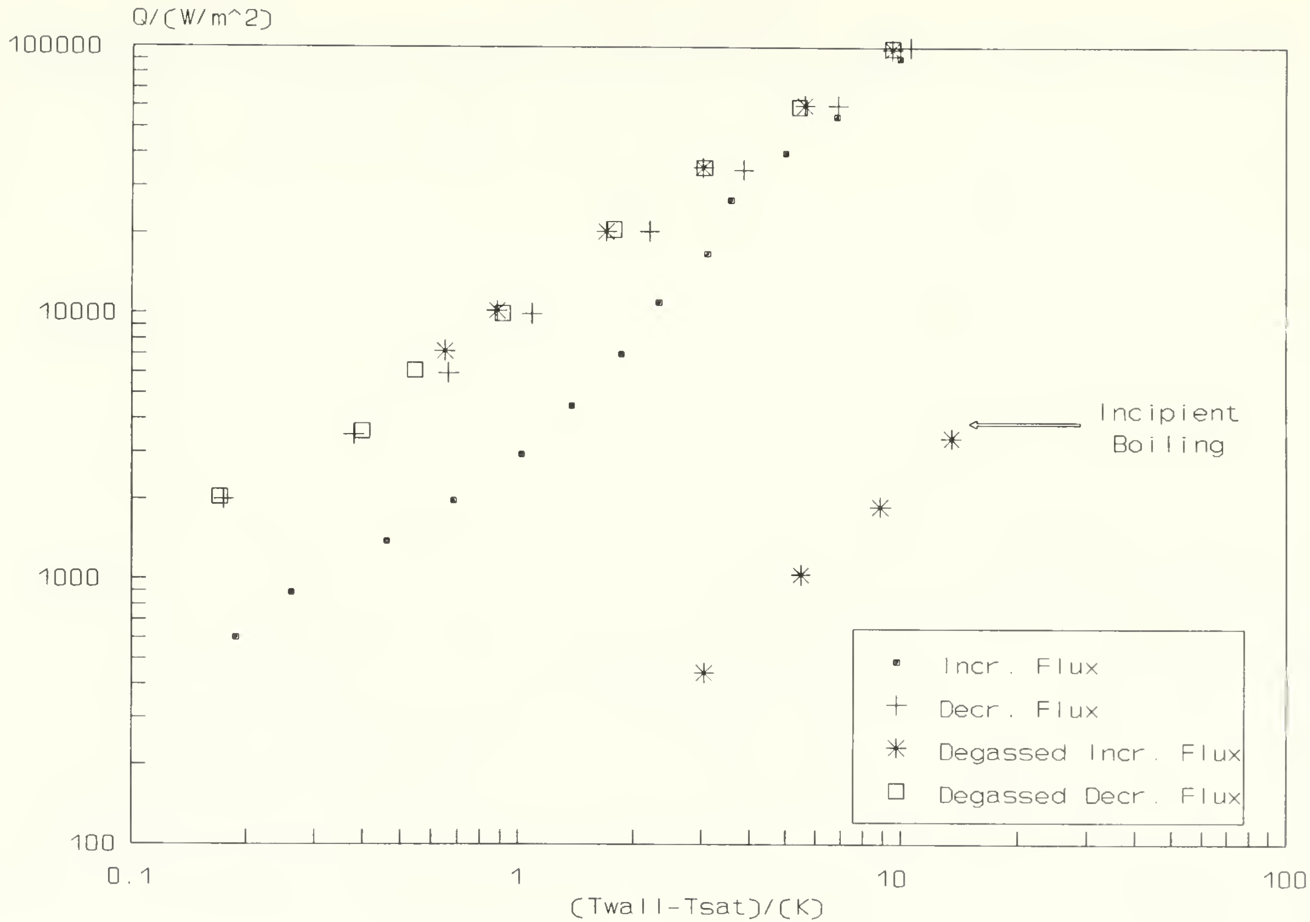


Figure 6.3 Performance Comparison For
Pure R-114 Boiling From Thermoexcel-E
Effect of De-gassing Surface/Fluid

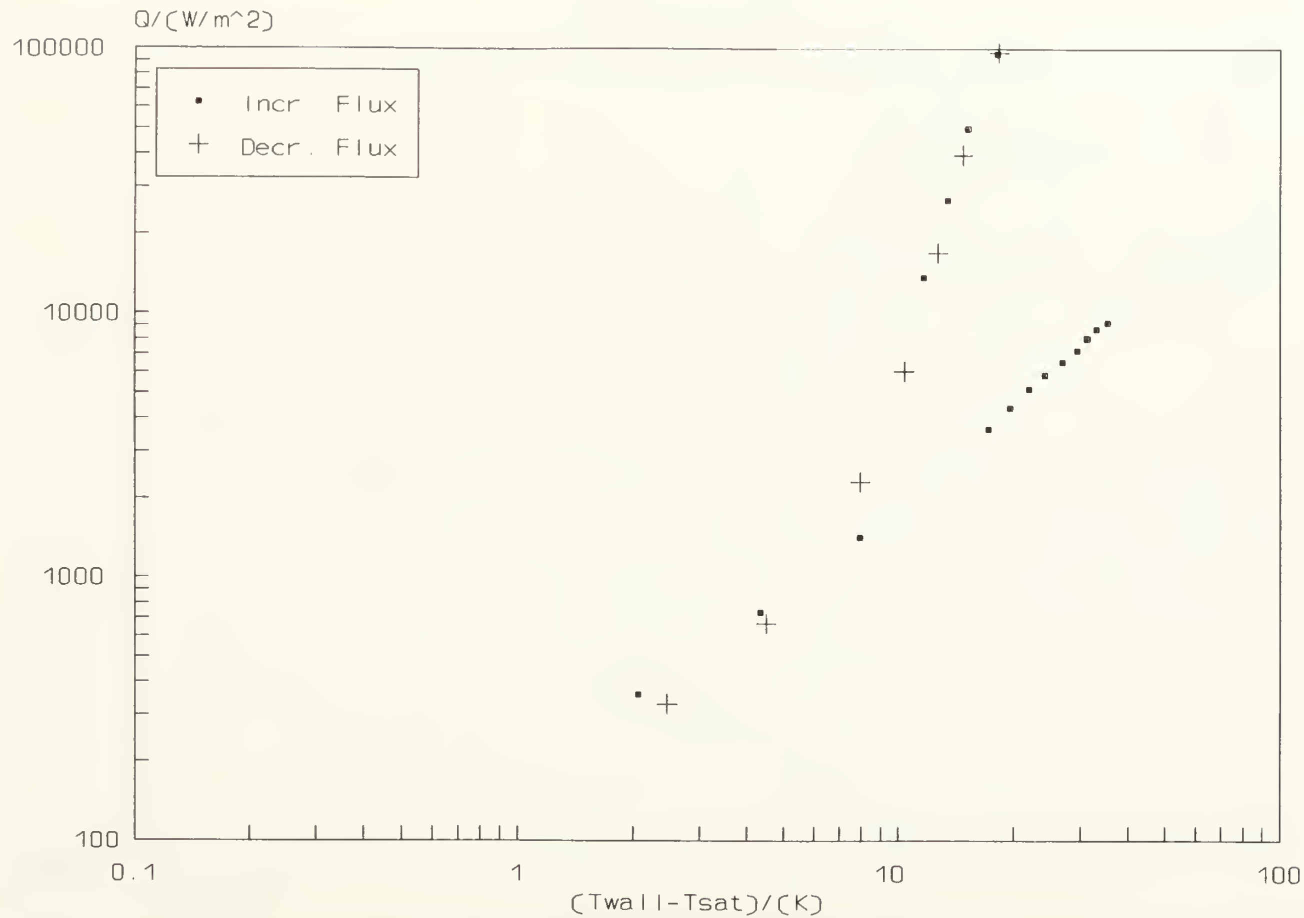


Figure 6.4 Performance Comparison for Pure R-114 Boiling From Smooth Tube Surface

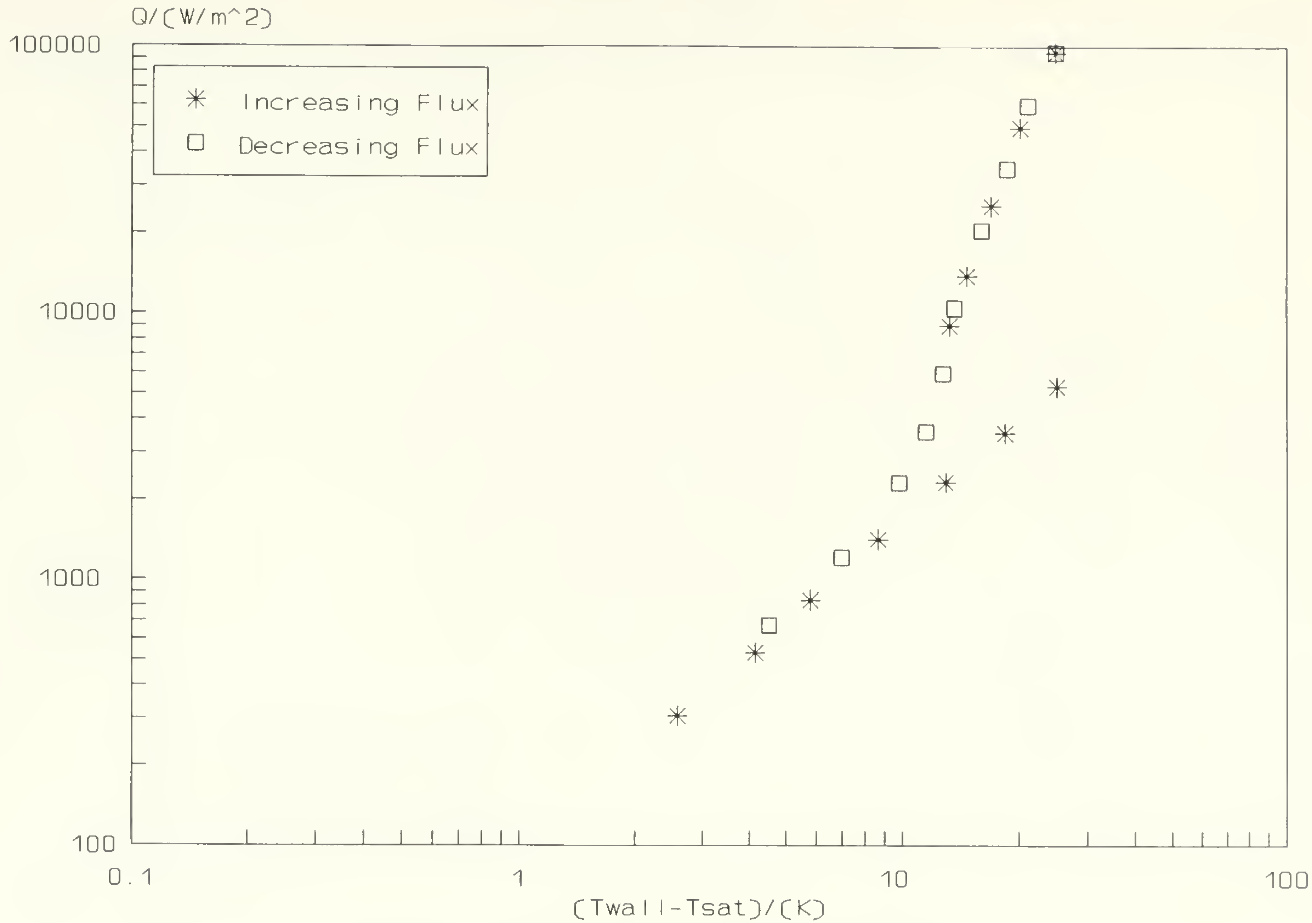


Figure 6.5 Performance Comparison for R-114/3% Oil Mixture Boiling From Smooth Tube Surface

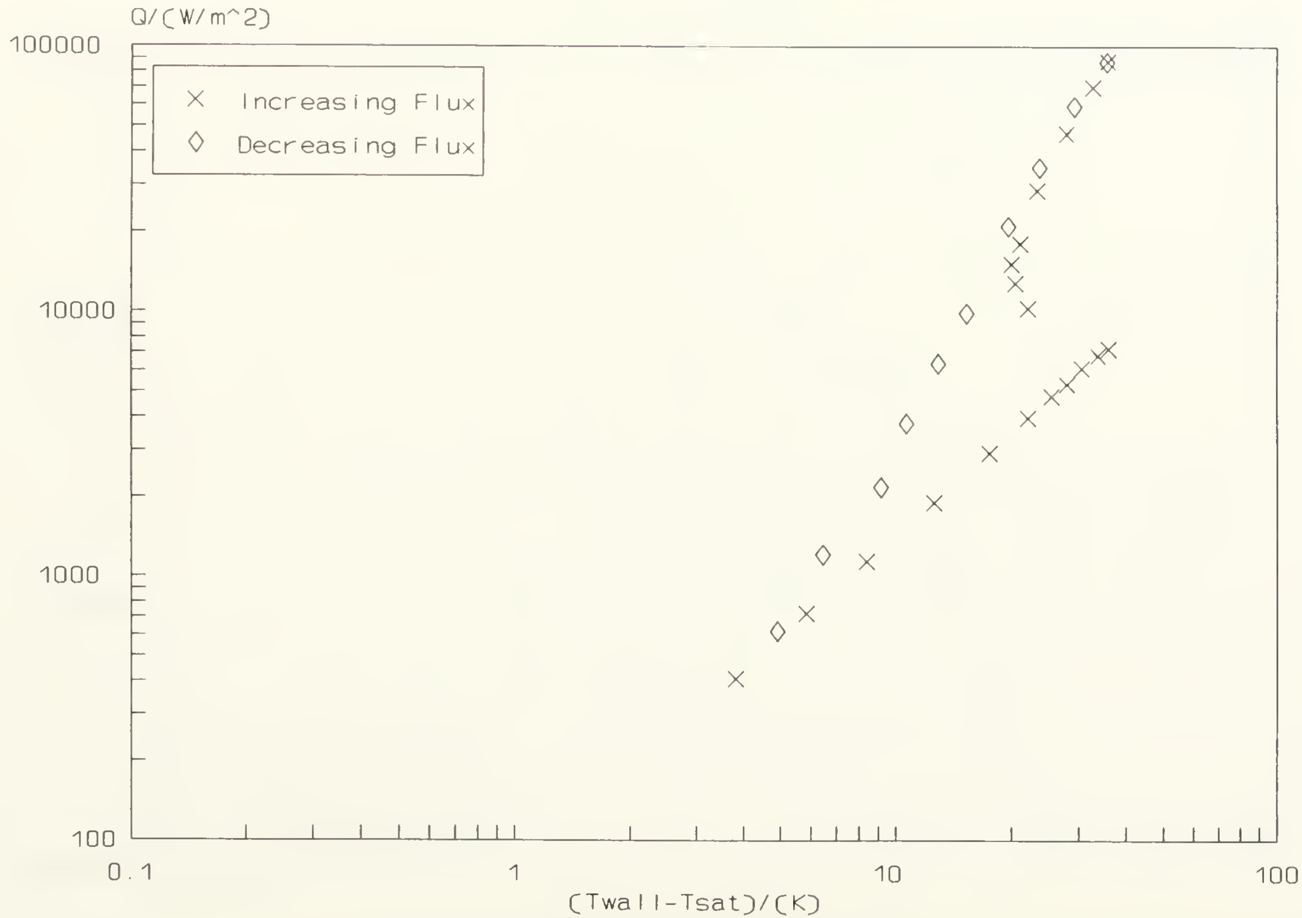


Figure 6.6 Performance Comparison for Pure R-114/10% Oil Mixture Boiling From Smooth Tube Surface

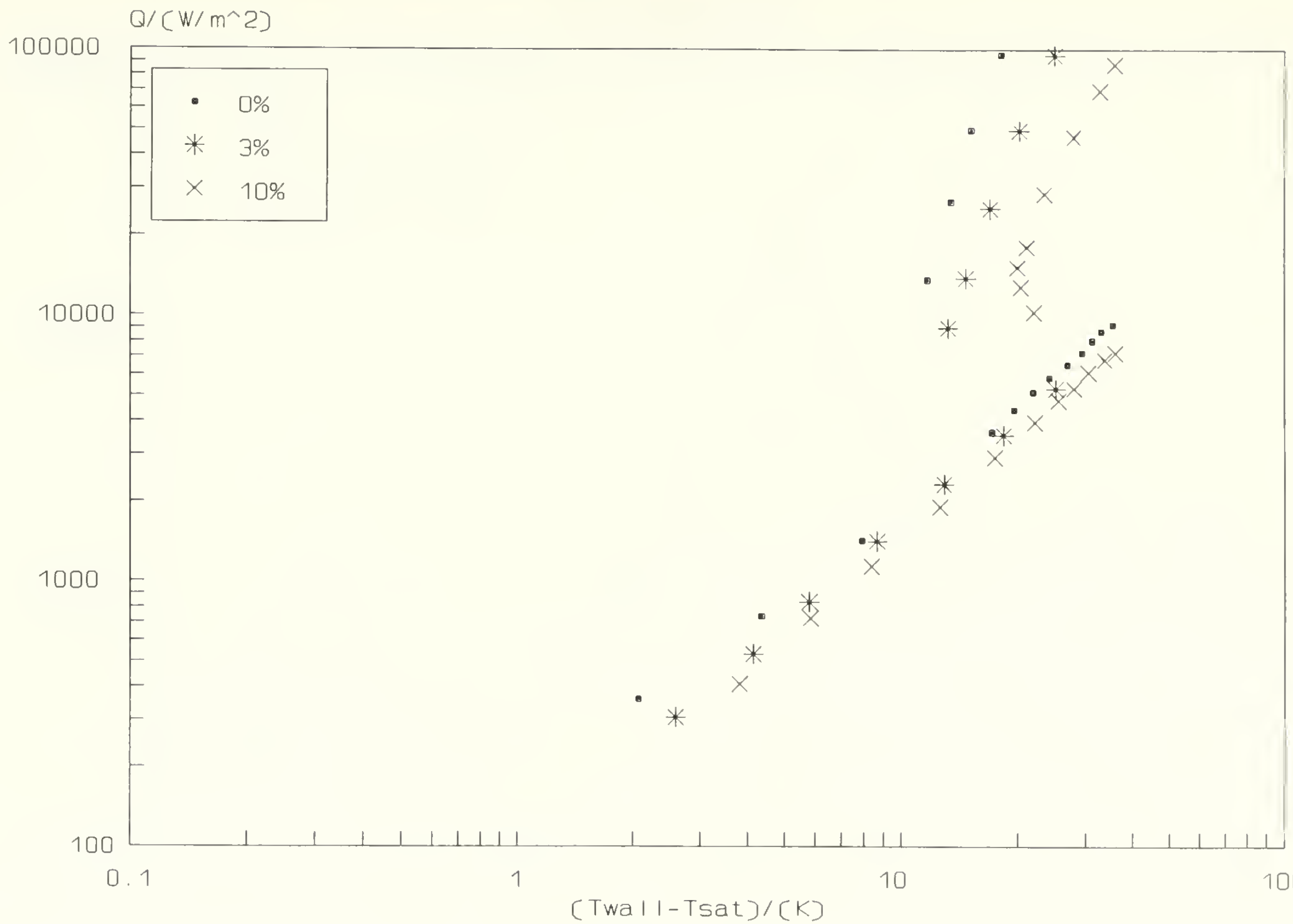


Figure 6.7 Performance Comparison for
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Increasing Flux From Smooth Tube

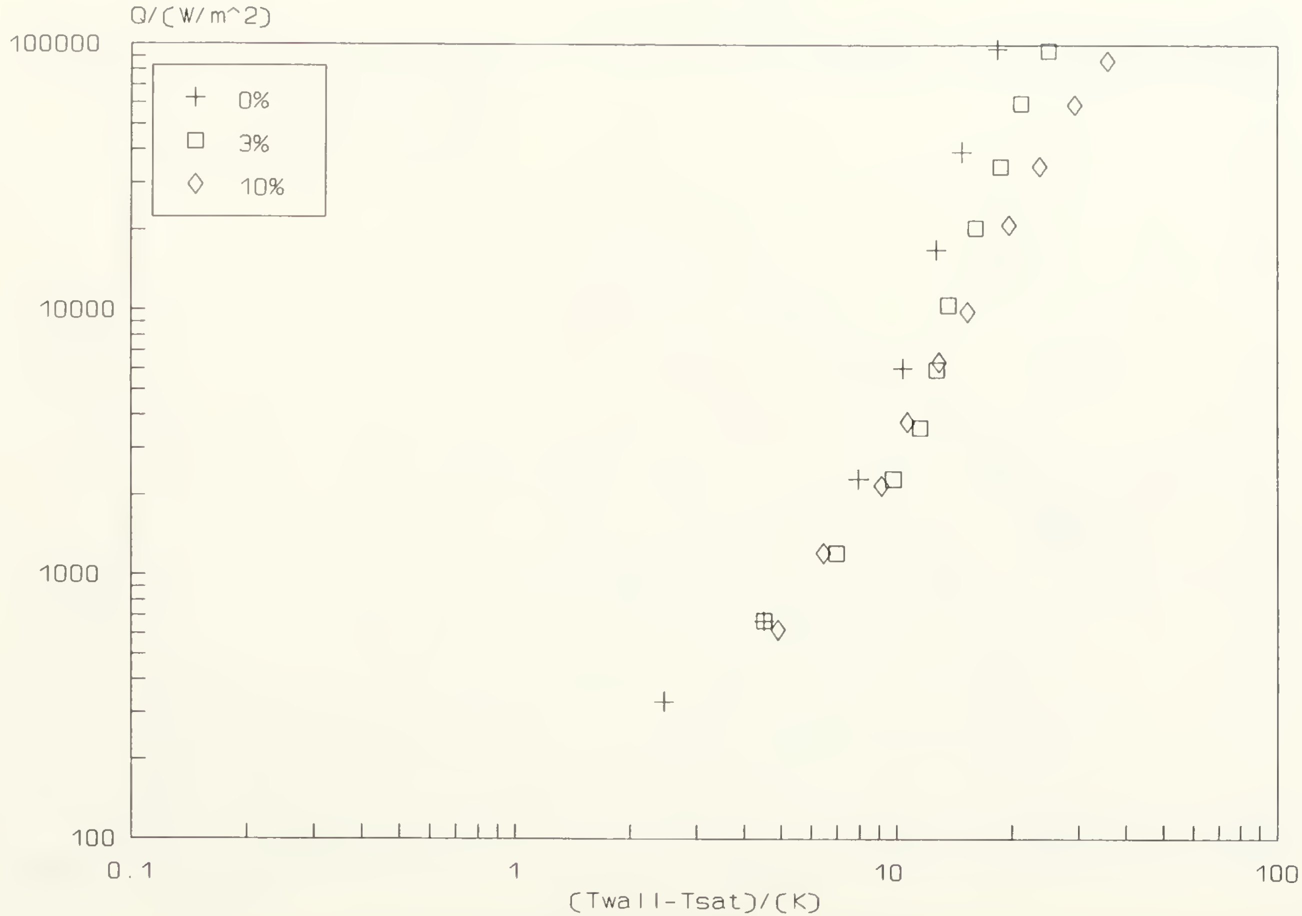


Figure 6.8 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Decreasing Flux From Smooth Tube Surface

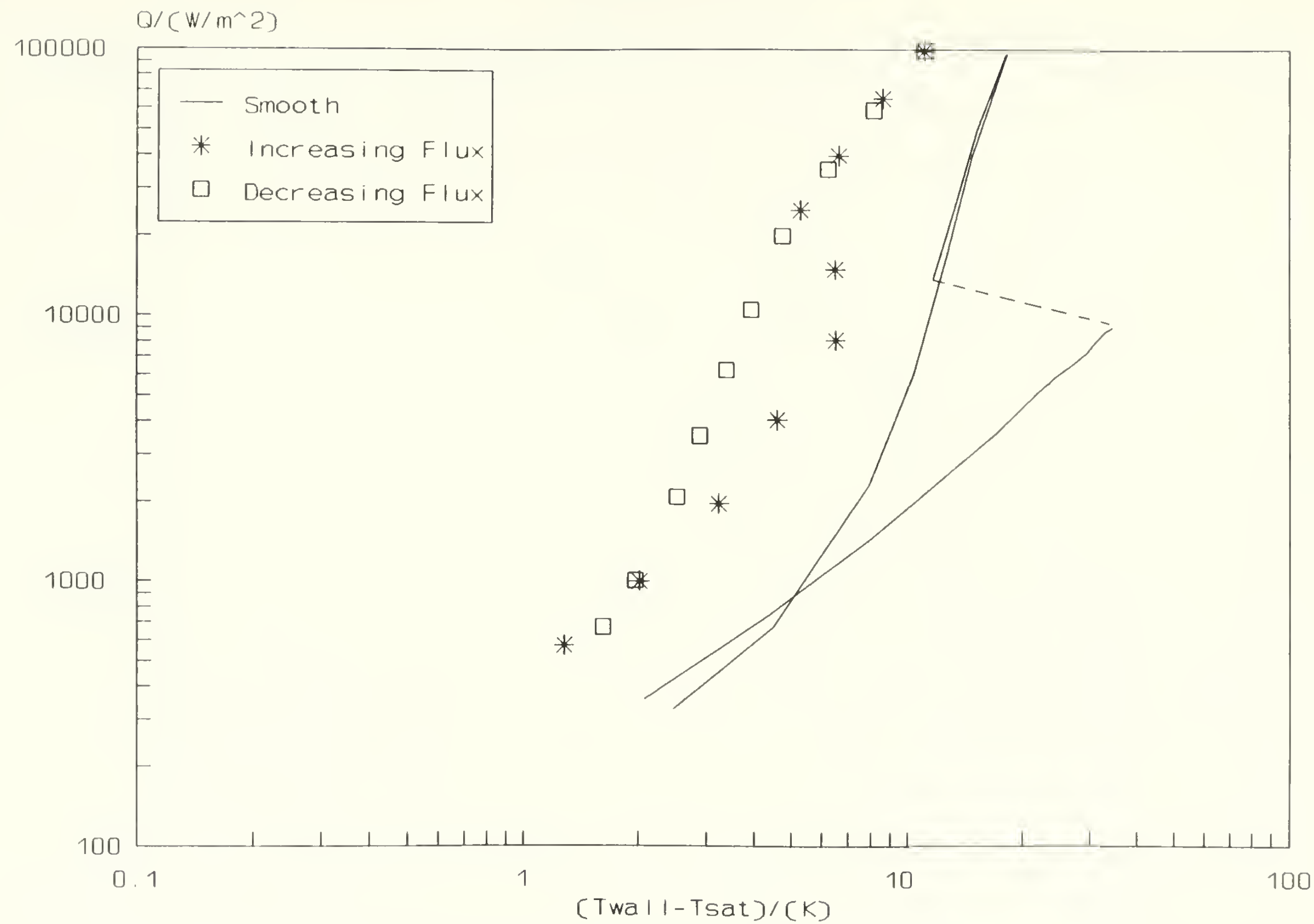


Figure 6.9 Performance Comparison For
Pure R-114 Boiling From
GEWA-K 26 fpi Tube

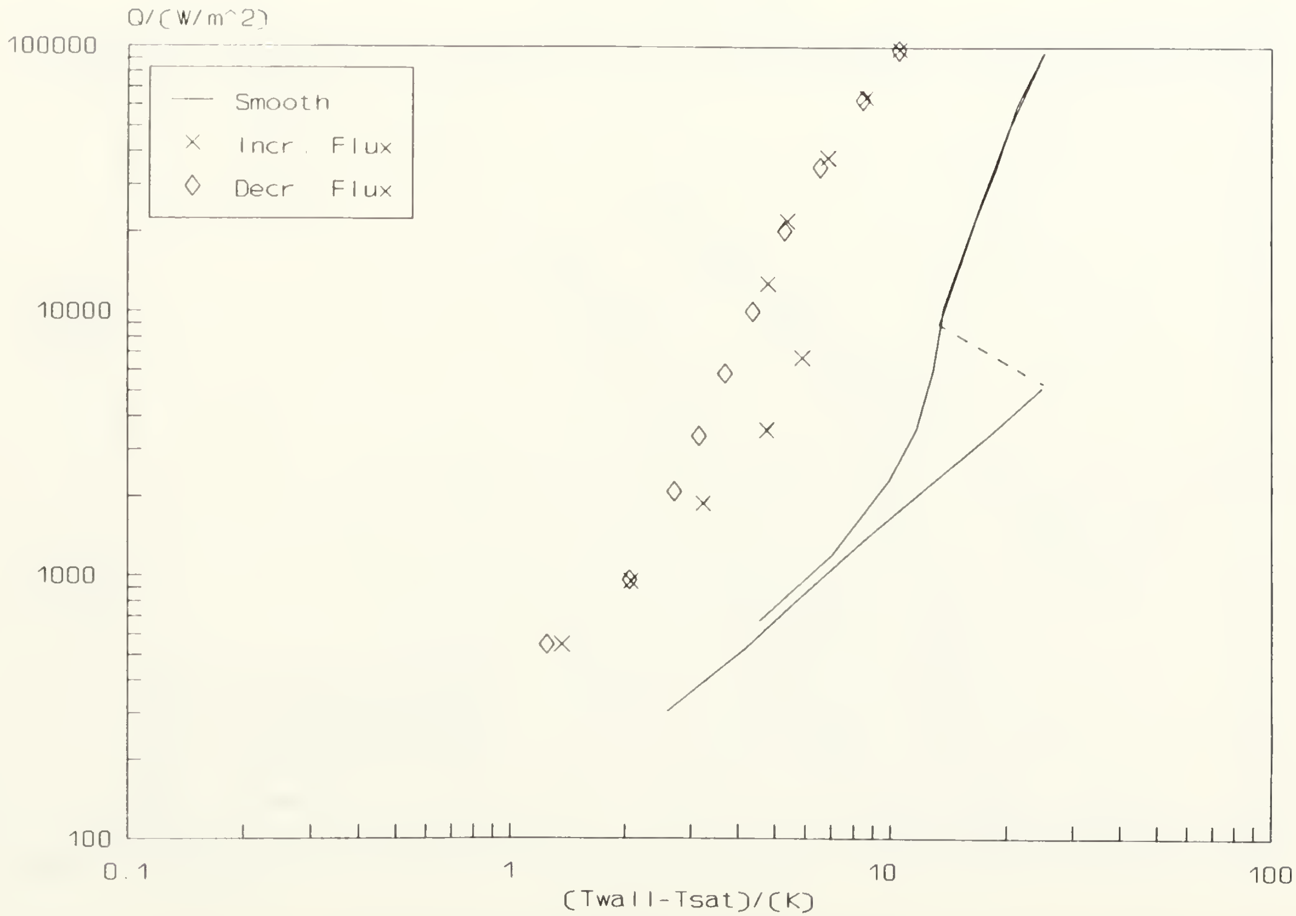


Figure 6.10 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-K 26 fpi Tube

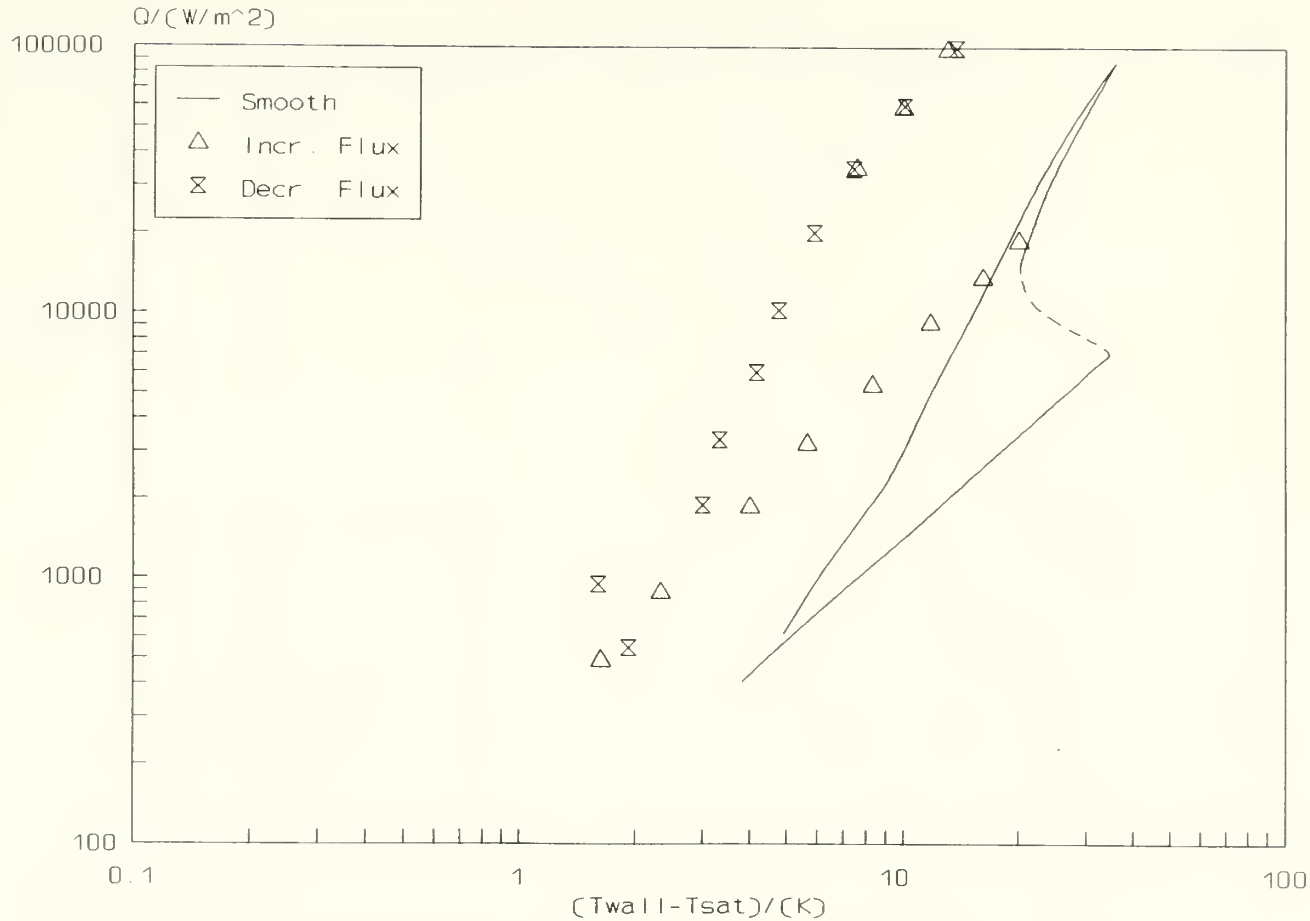


Figure 6.11 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-K 26 fpi Tube

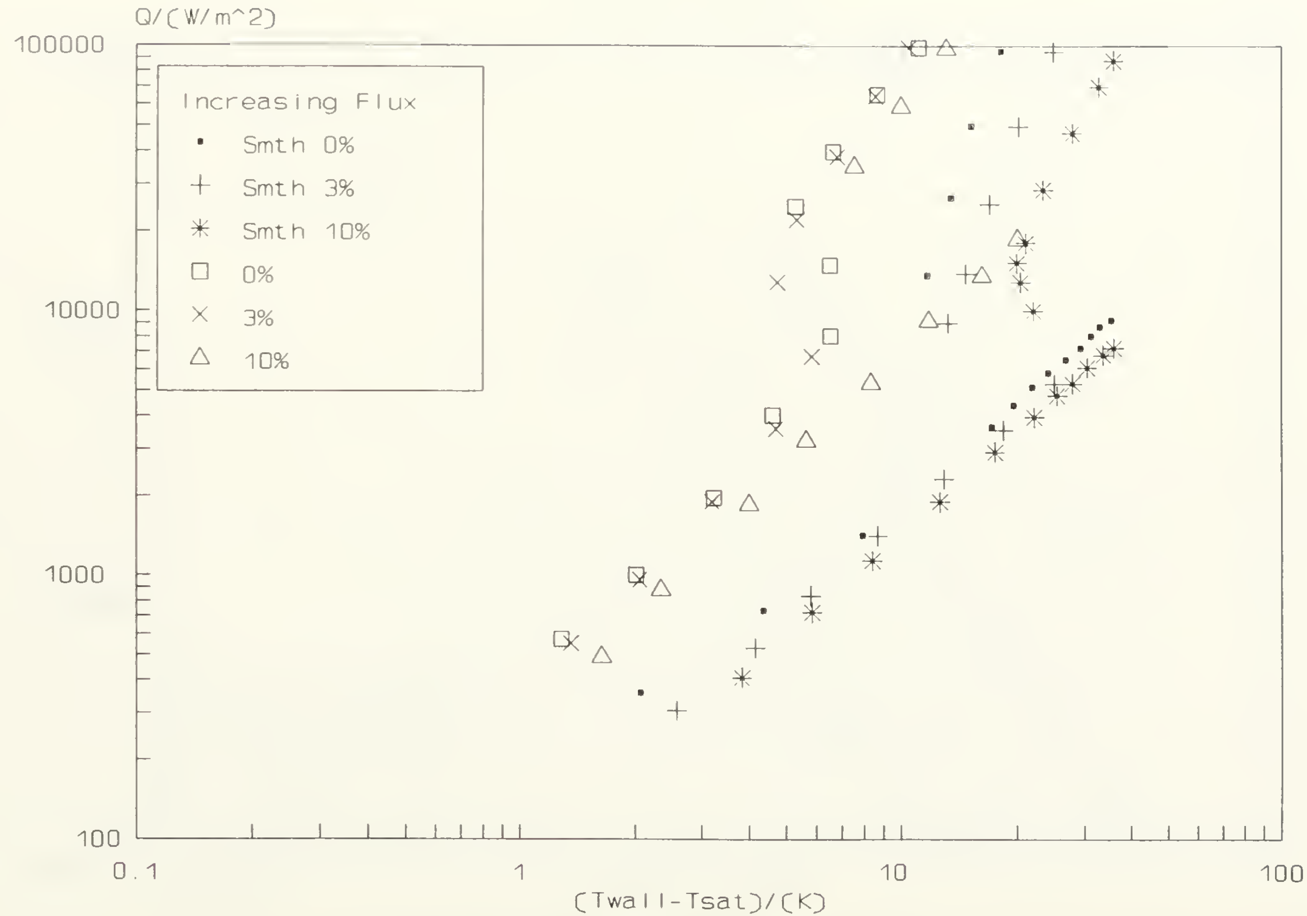


Figure 6.12 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-K 26 fpi Tube

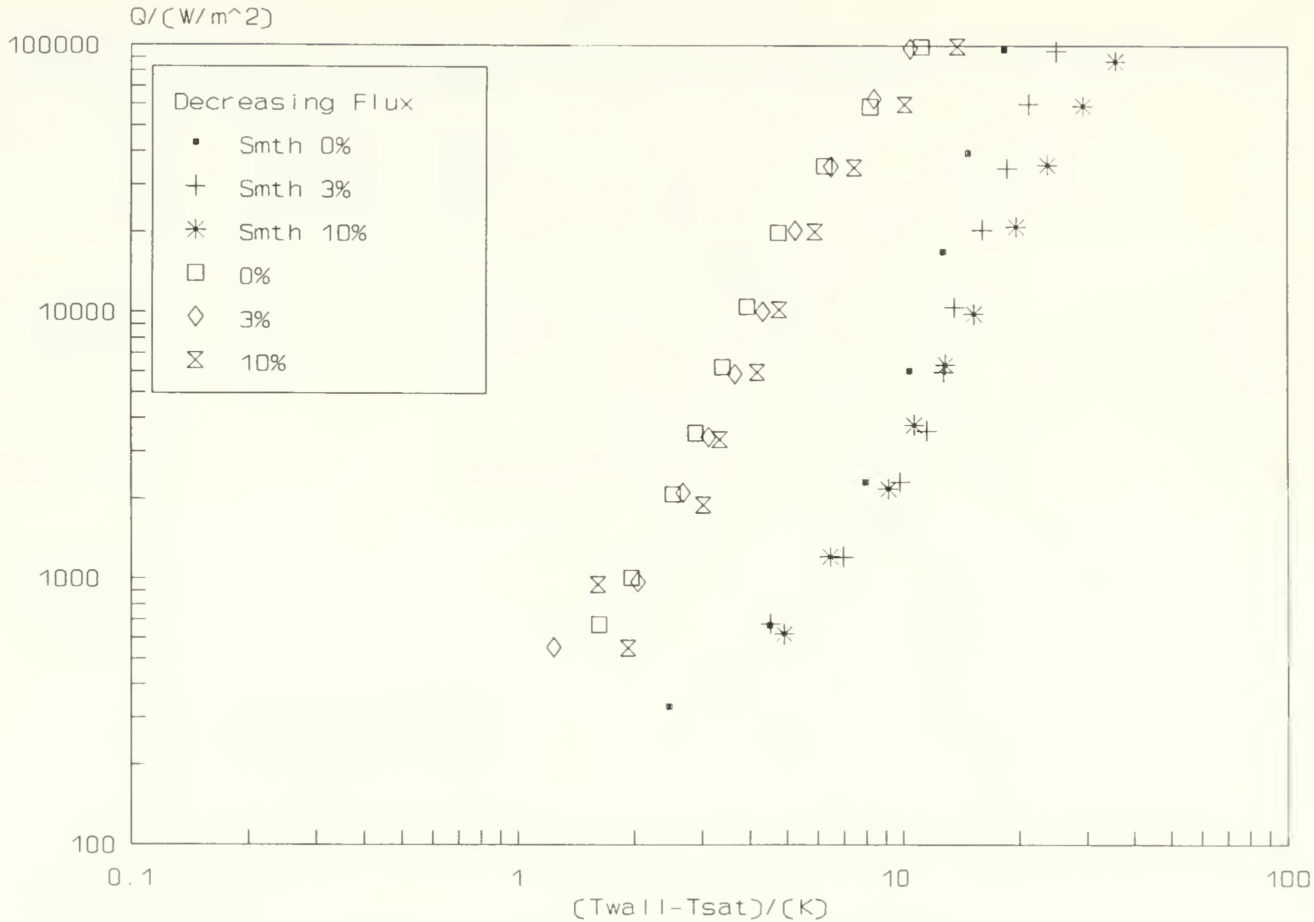


Figure 6.13 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-K 26 fpi Tube

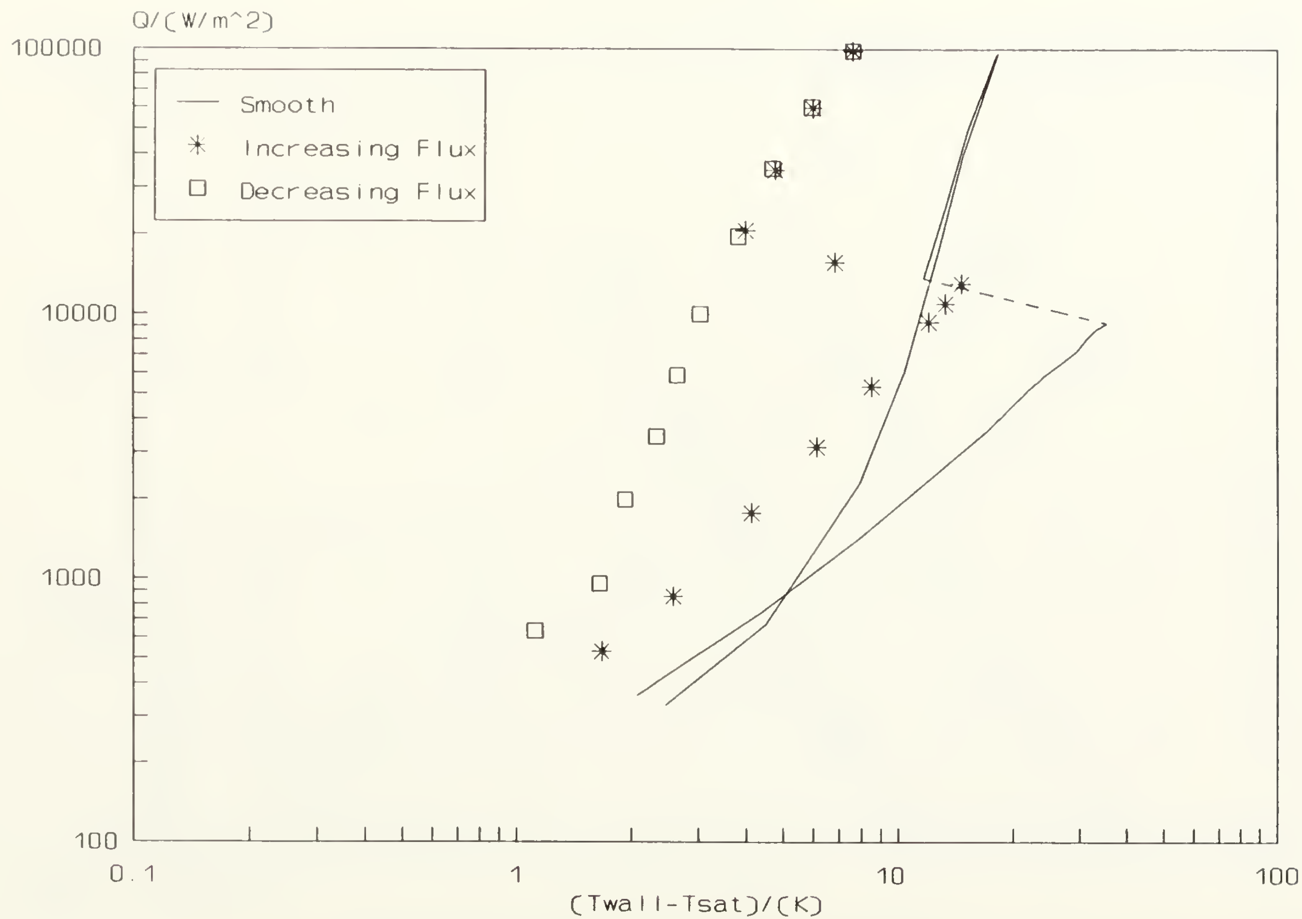


Figure 6.14 Performance Comparison For
Pure R-114 Boiling From
GEWA-K 40 fpi Tube

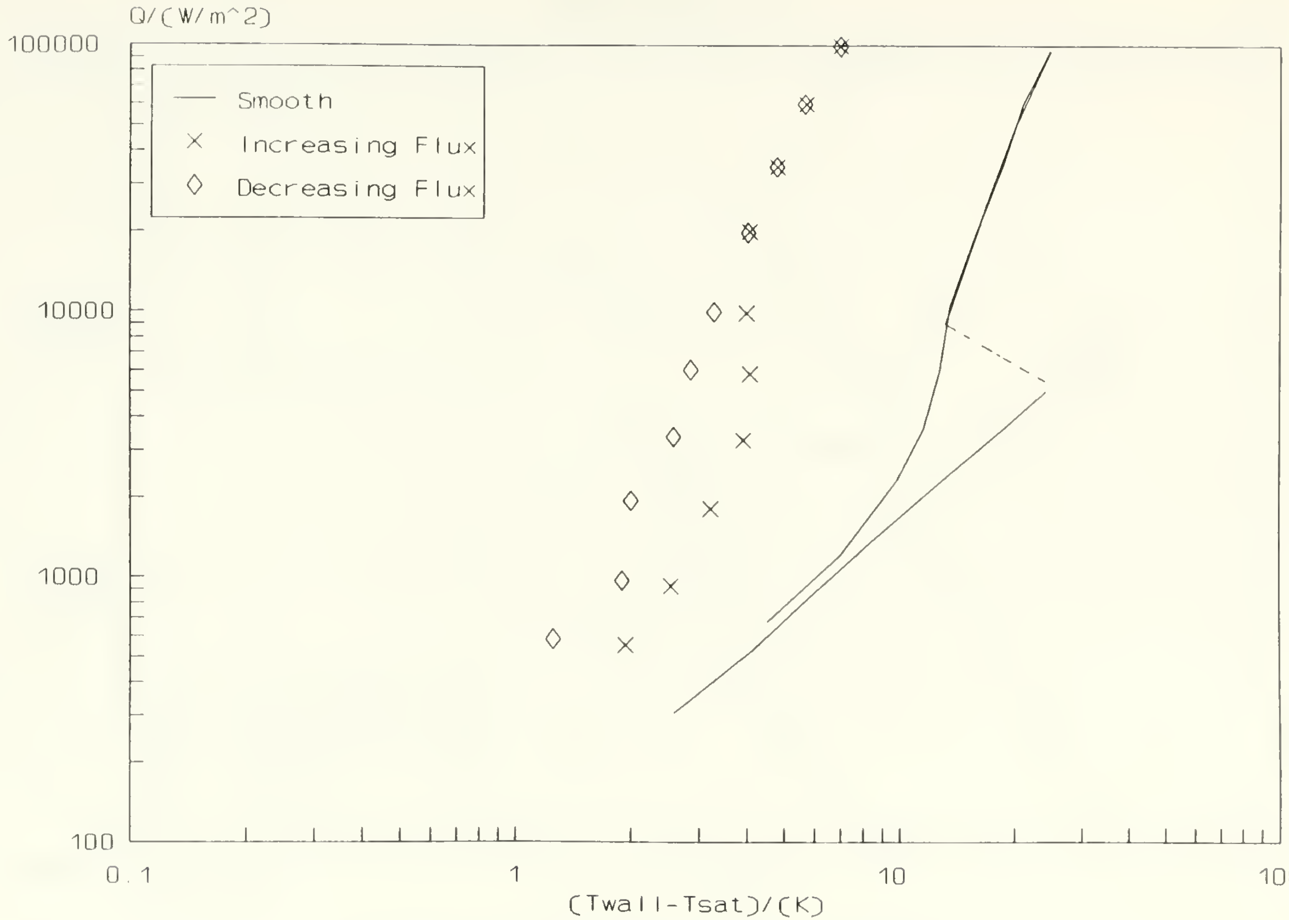


Figure 6.15 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-K 40 fpi Tube

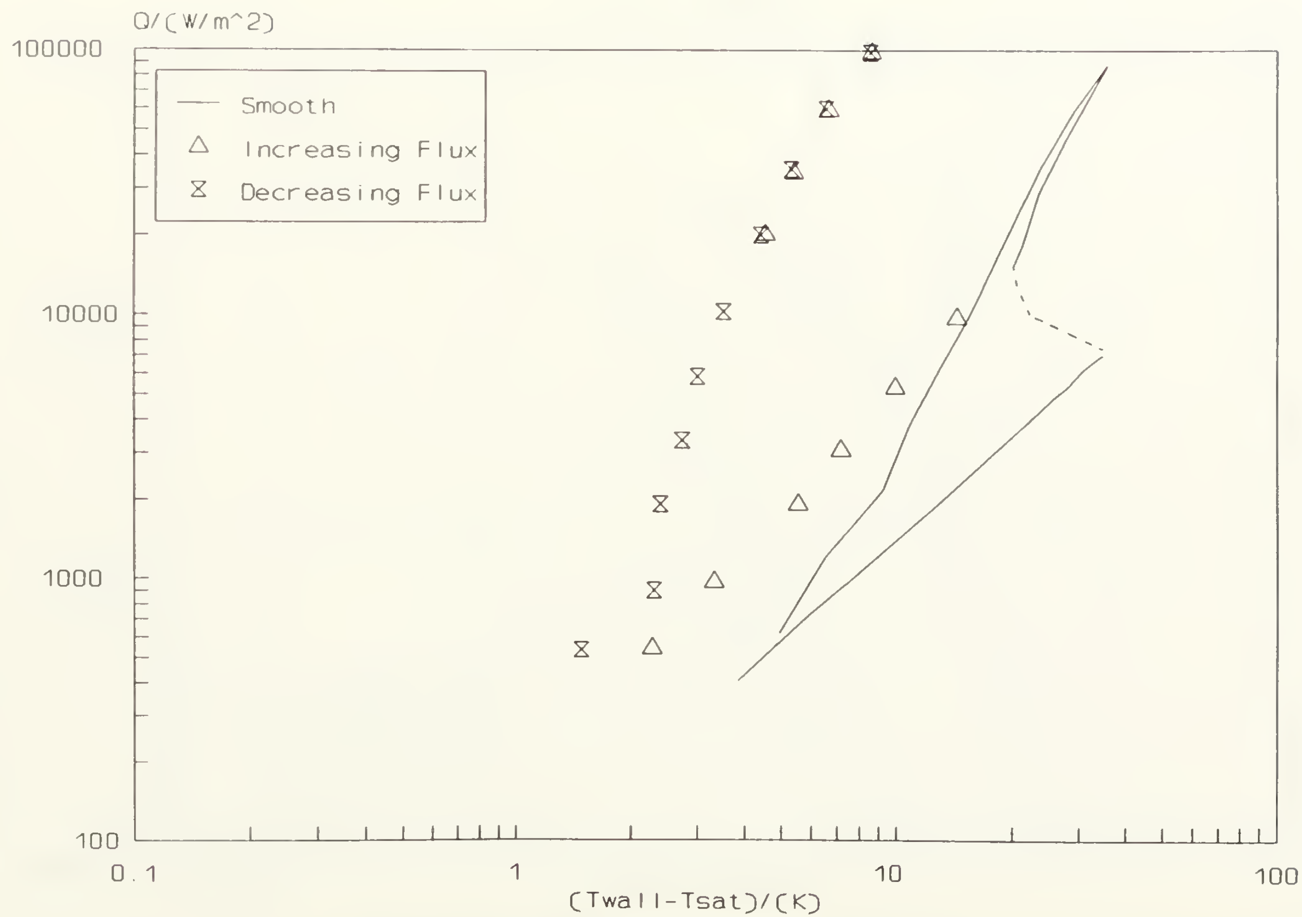


Figure 6-16 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-K 40 fpi Tube

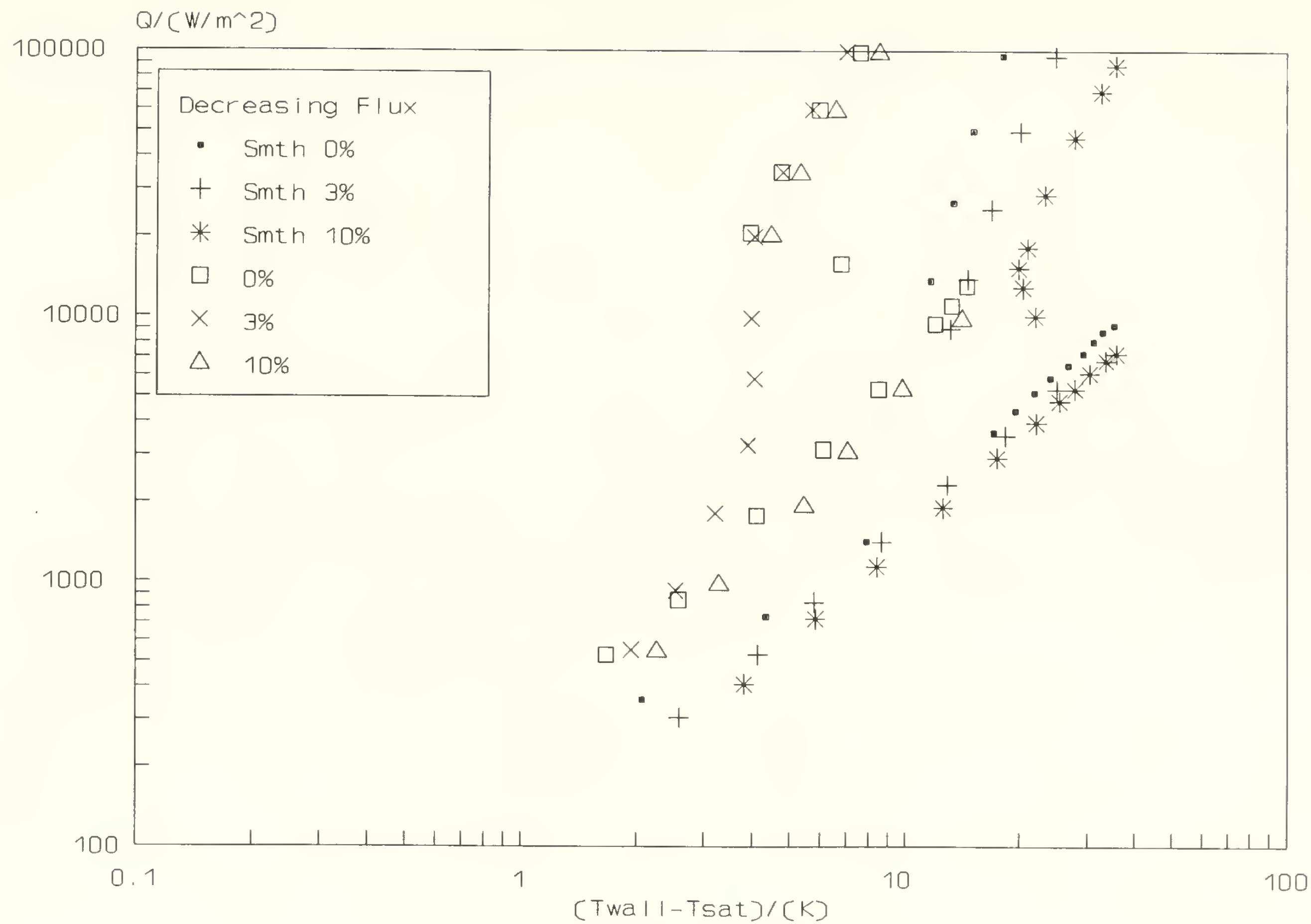


Figure 6.17 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-K 40 fpi Tube

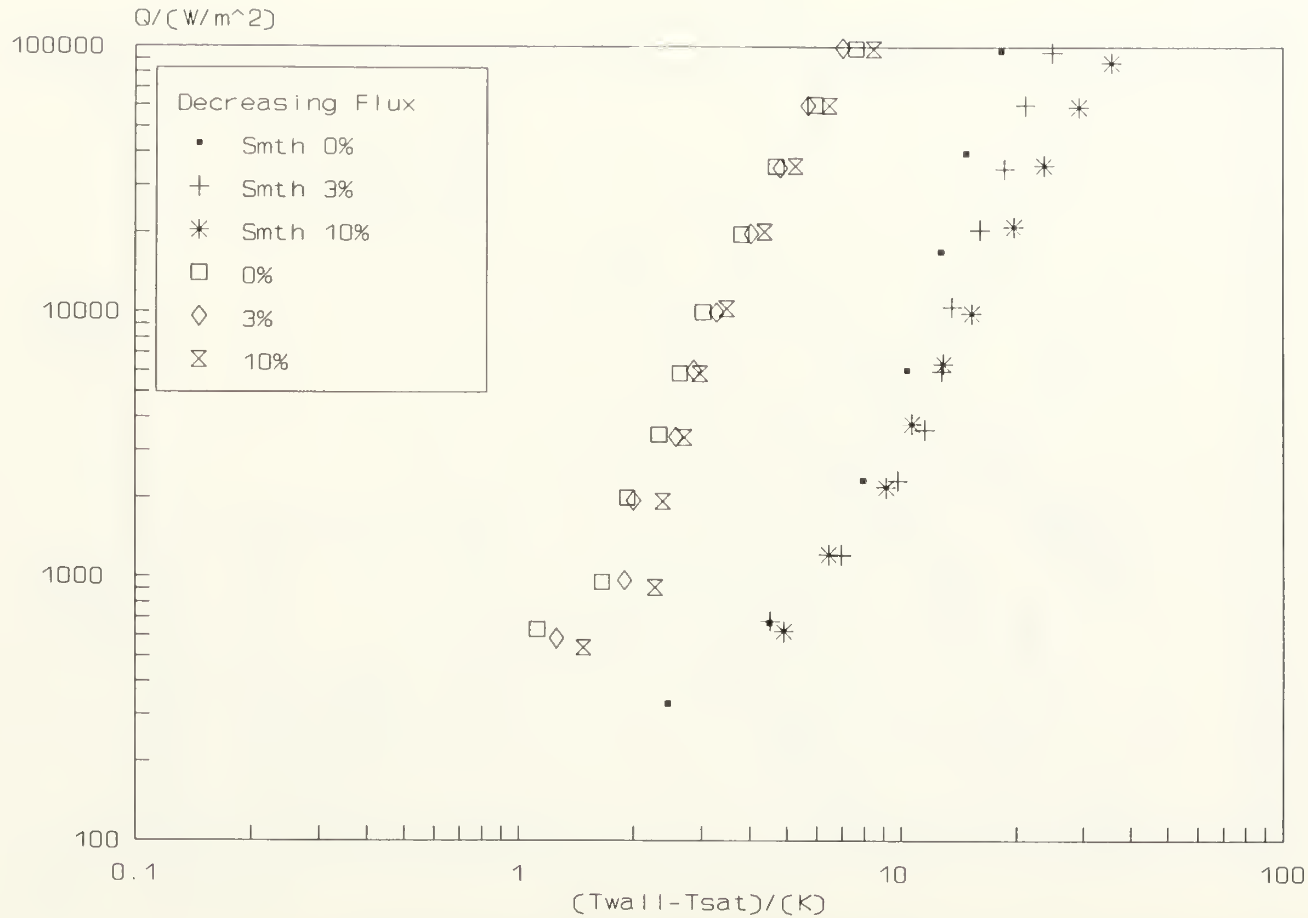


Figure 6.18 Performance Comparison For
Boiling R-114/0%, 3% & 10% Oil Mixtures
From GEWA-K 40 fpi Tube

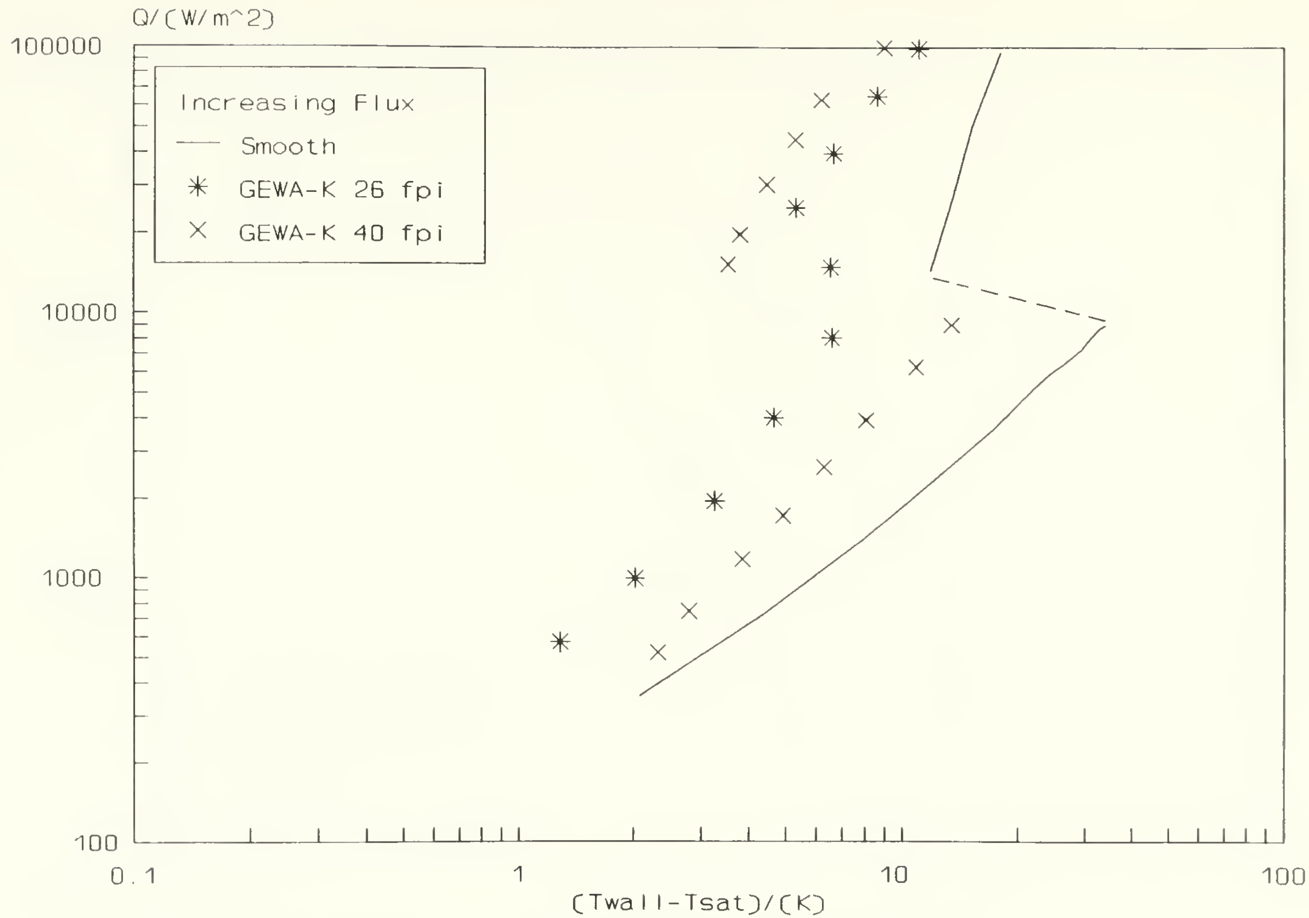


Figure 6.19 Performance Comparison For
Boiling Pure R-114 From
GEWA-K 26/40 fpi Tubes

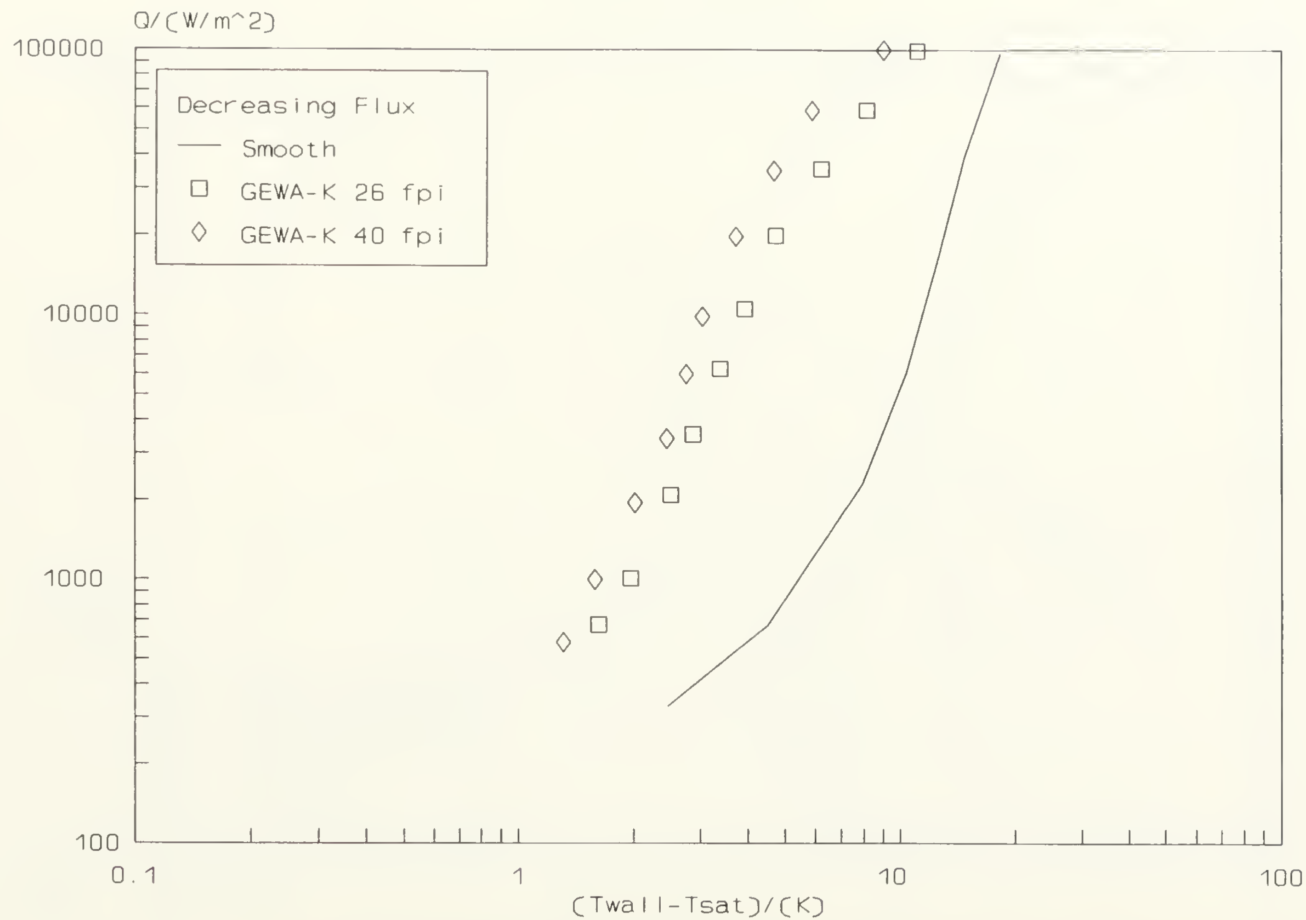


Figure 6.20 Performance Comparison For Boiling Pure R-114 From GEWA-K 26/40 fpi Tubes

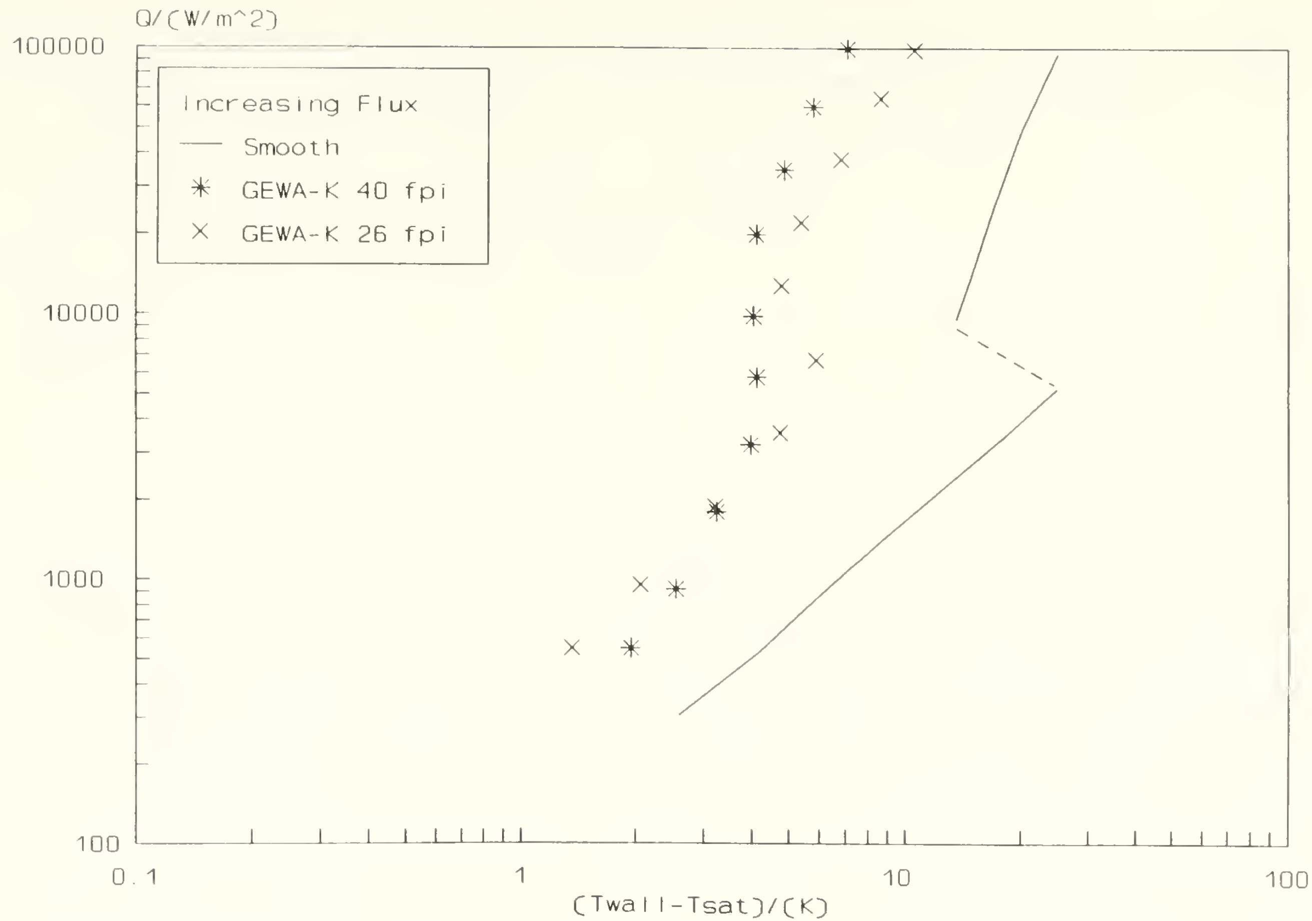


Figure 6.21 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-K 26/40 fpi Tubes

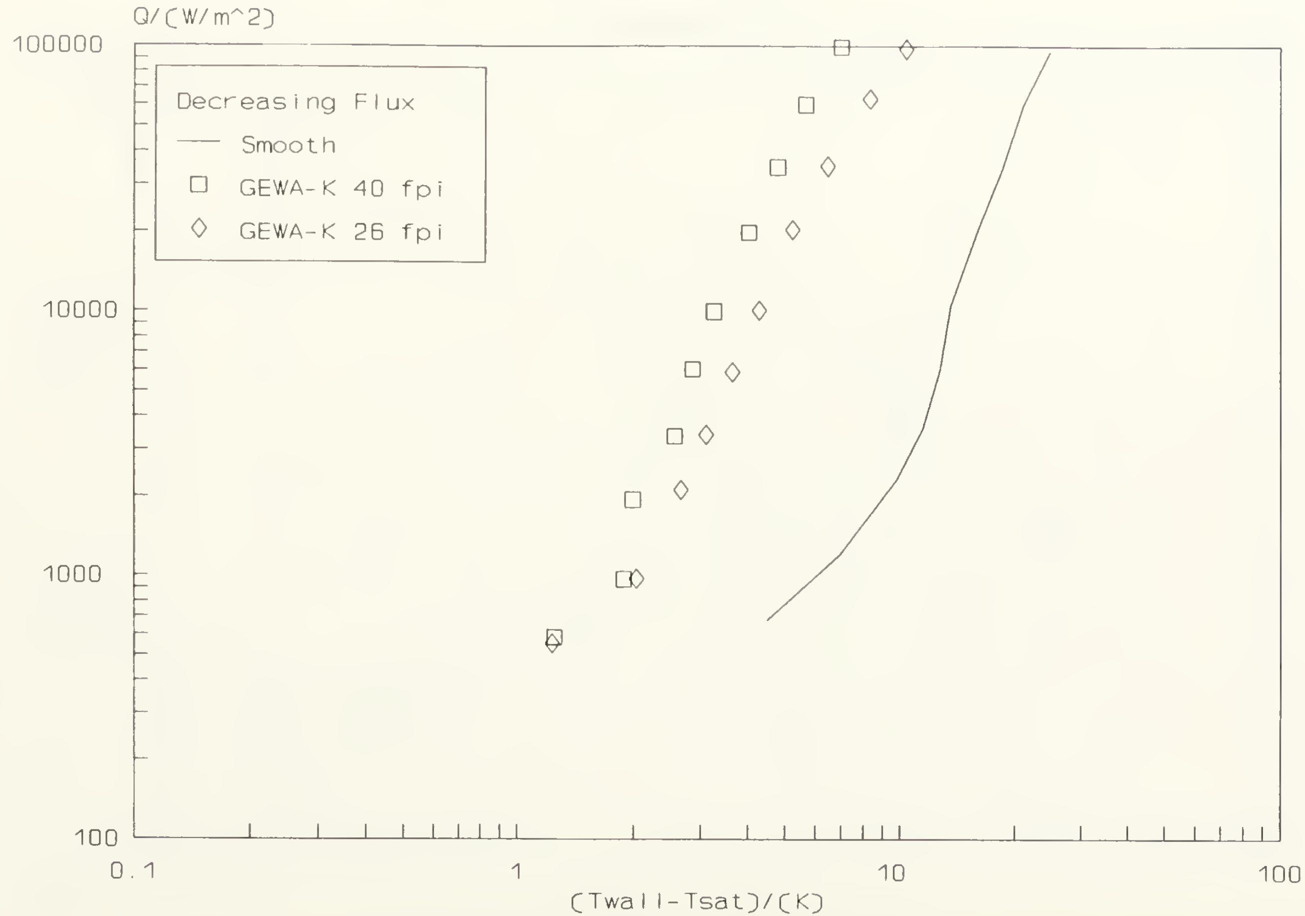


Figure 6.22 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-K 26/40 fpi Tubes

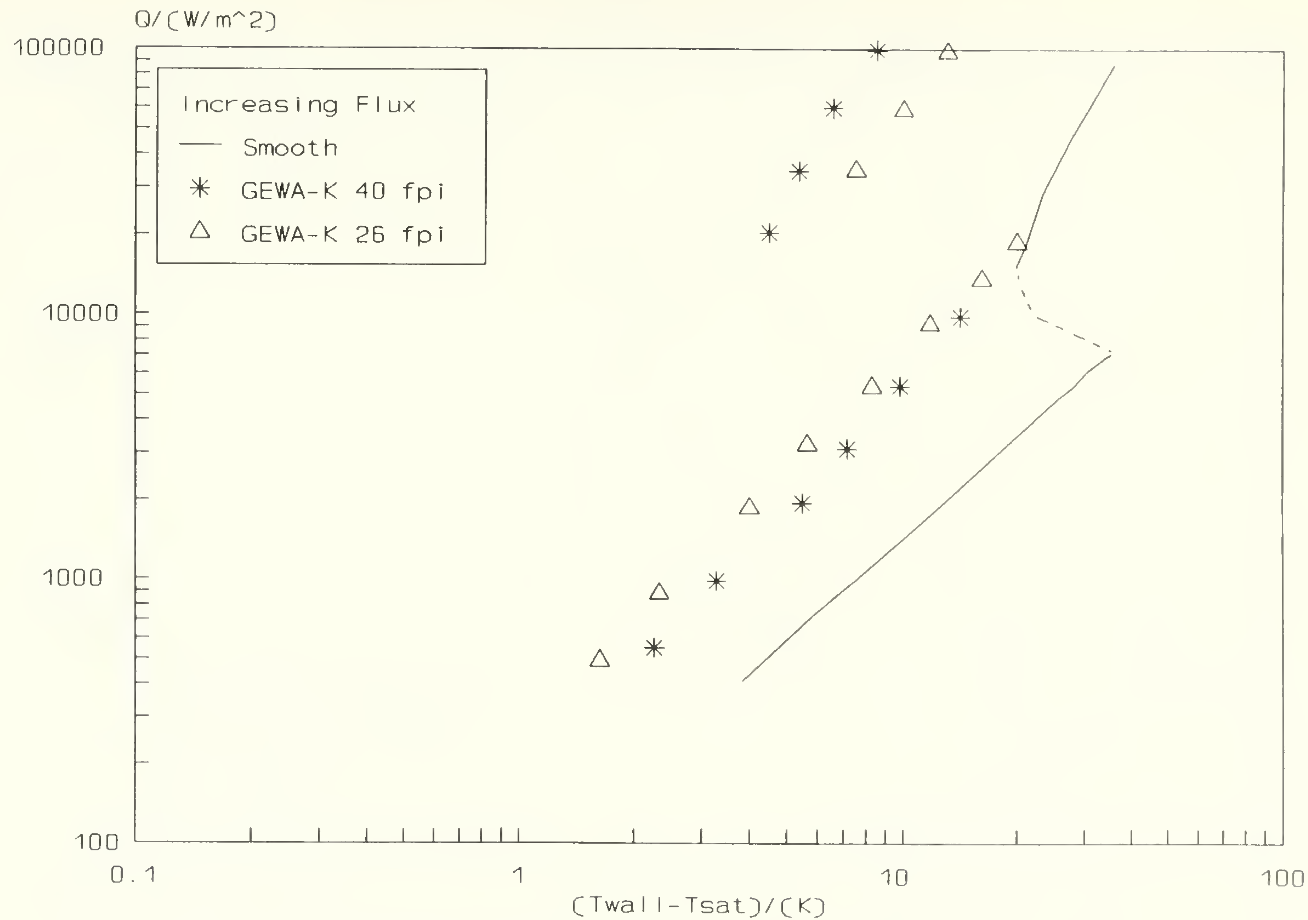


Figure 6.23 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-K 26/40 fpi Tubes

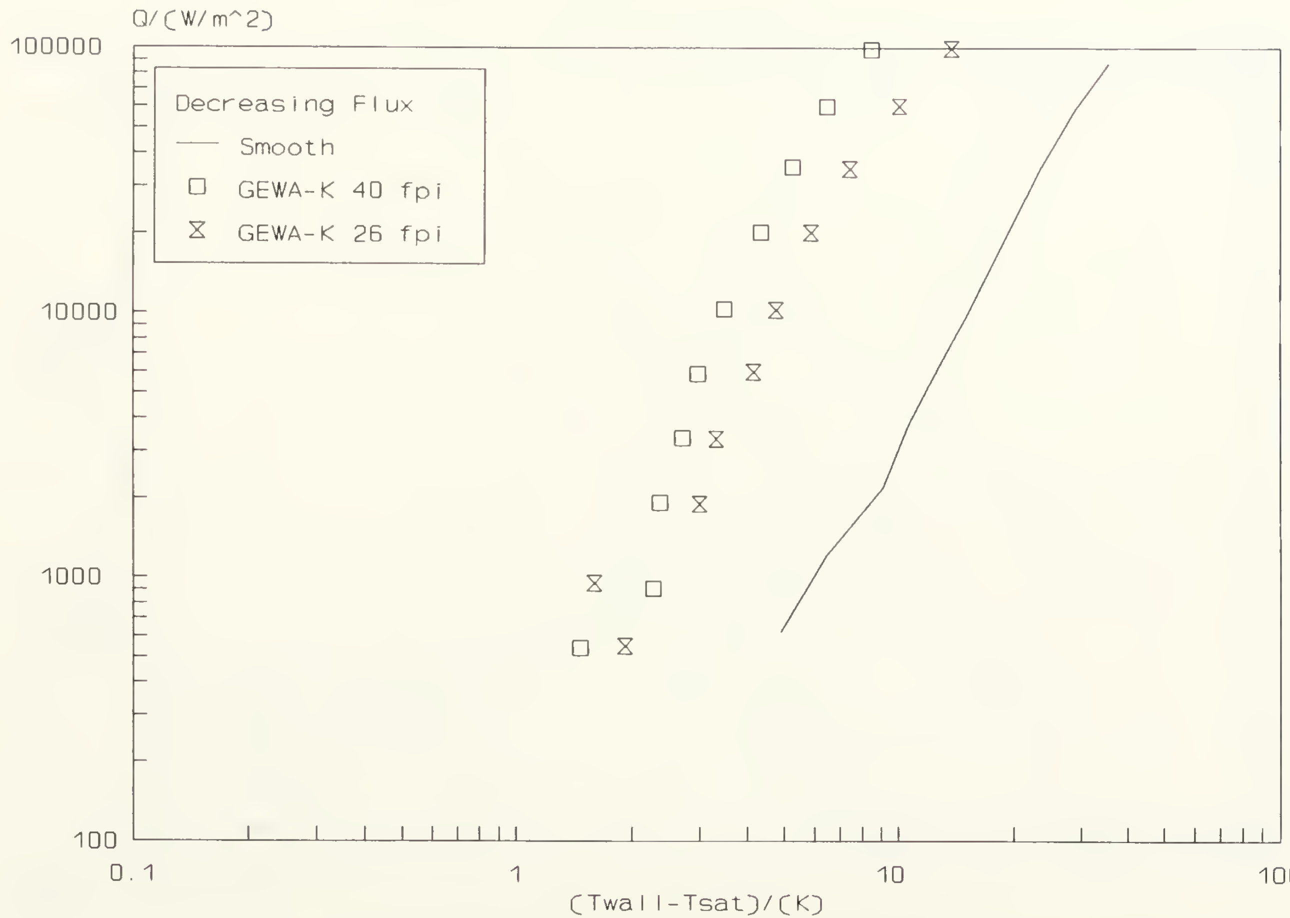


Figure 6.24 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-K 26/40 fpi Tubes

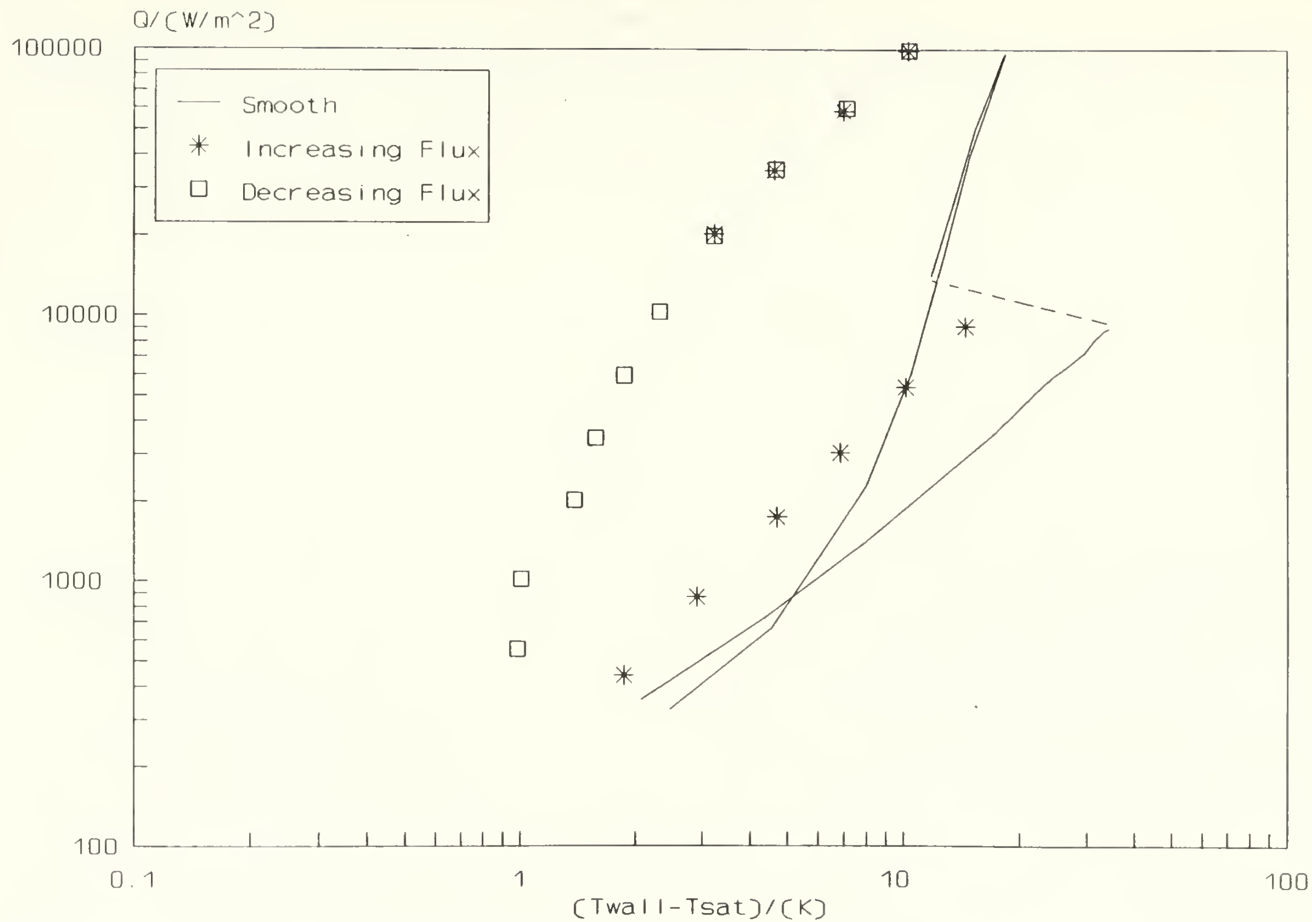


Figure 6.25 Performane Comparison For
Pure R-114 Boiling From
GEWA-T 19 fpi Tube

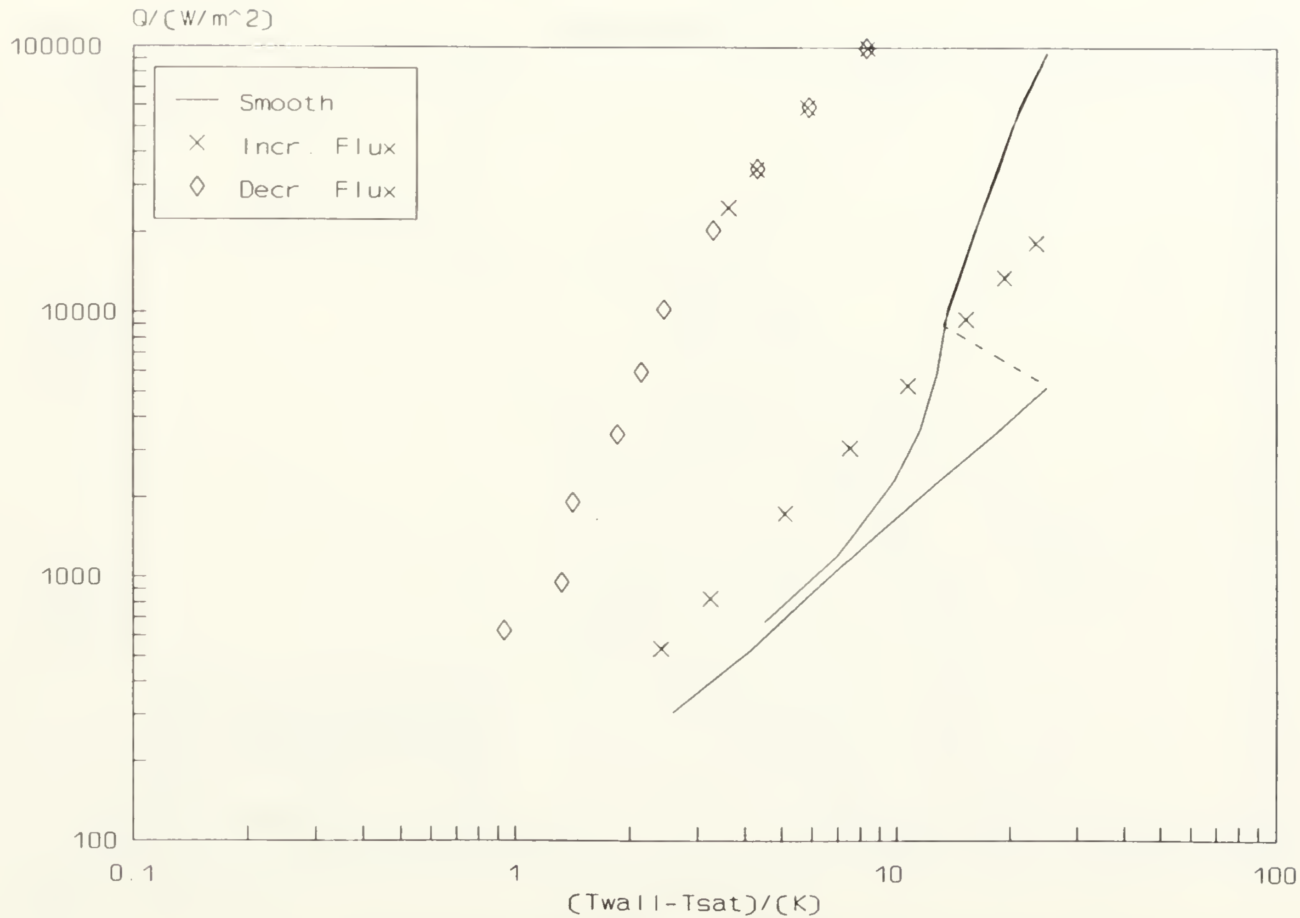


Figure 6.26 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-T 19 fpi Tube

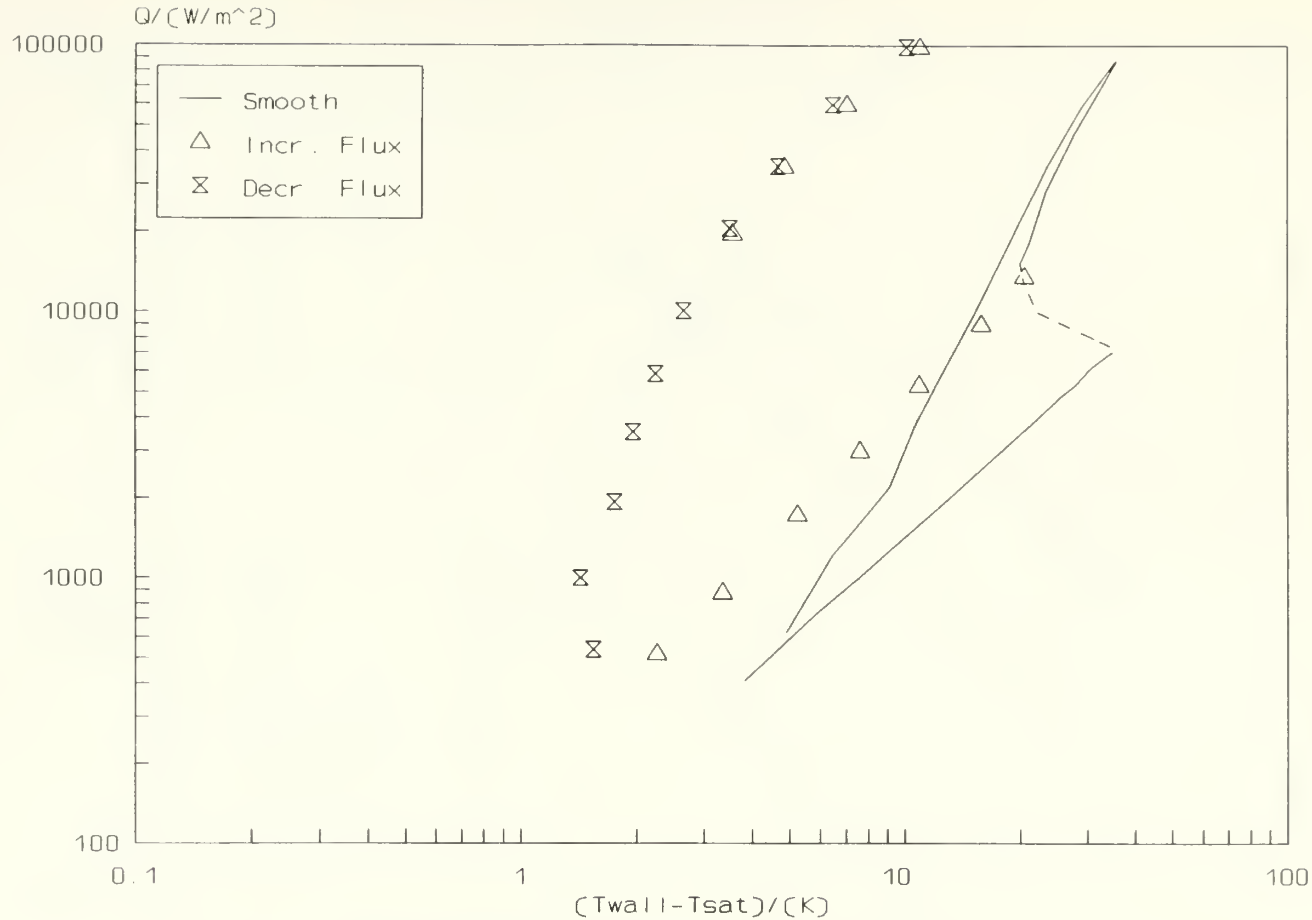


Figure 6.27 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-T 19 fpi Tube

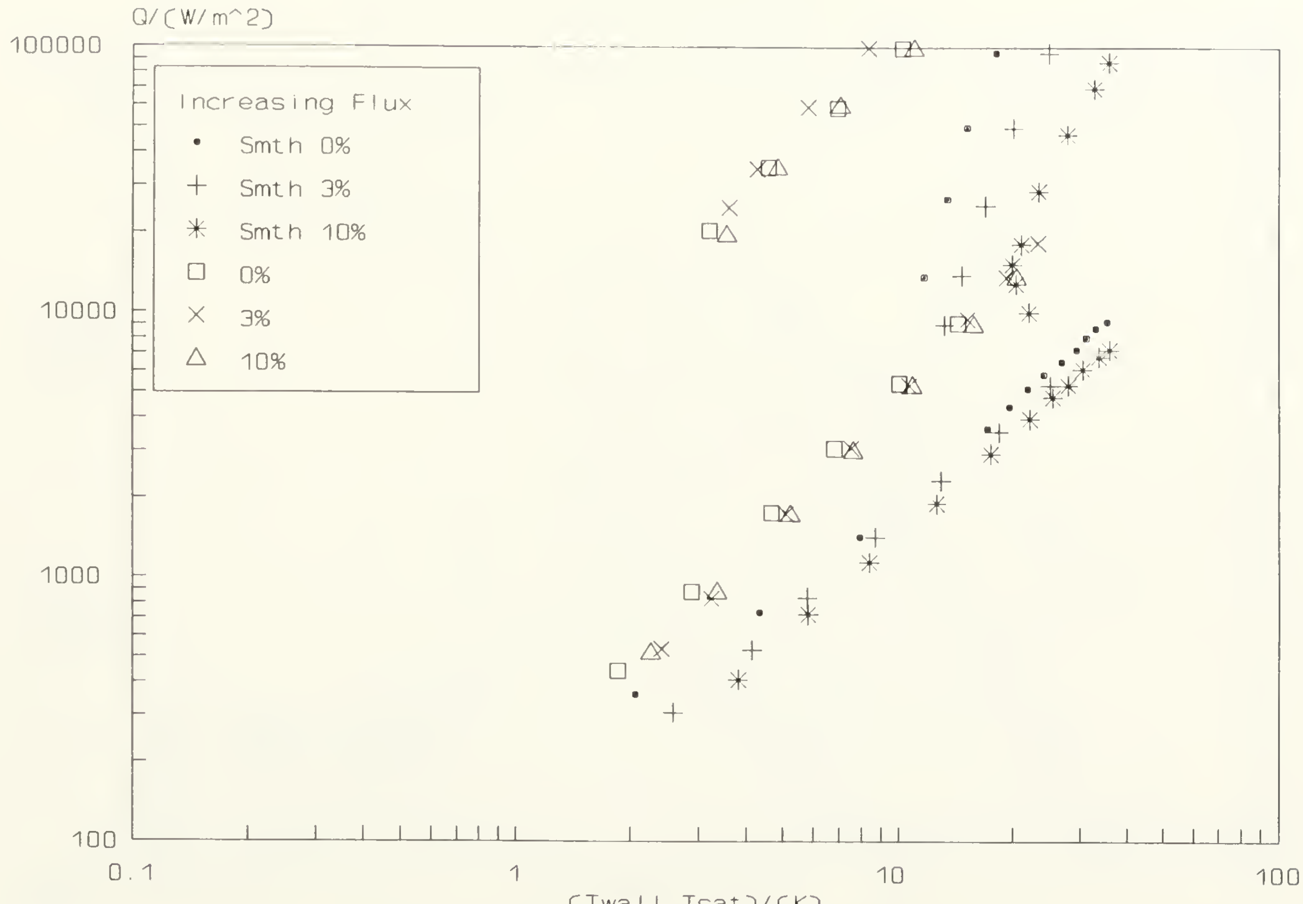


Figure 6.28 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-T 19 fpi Tube

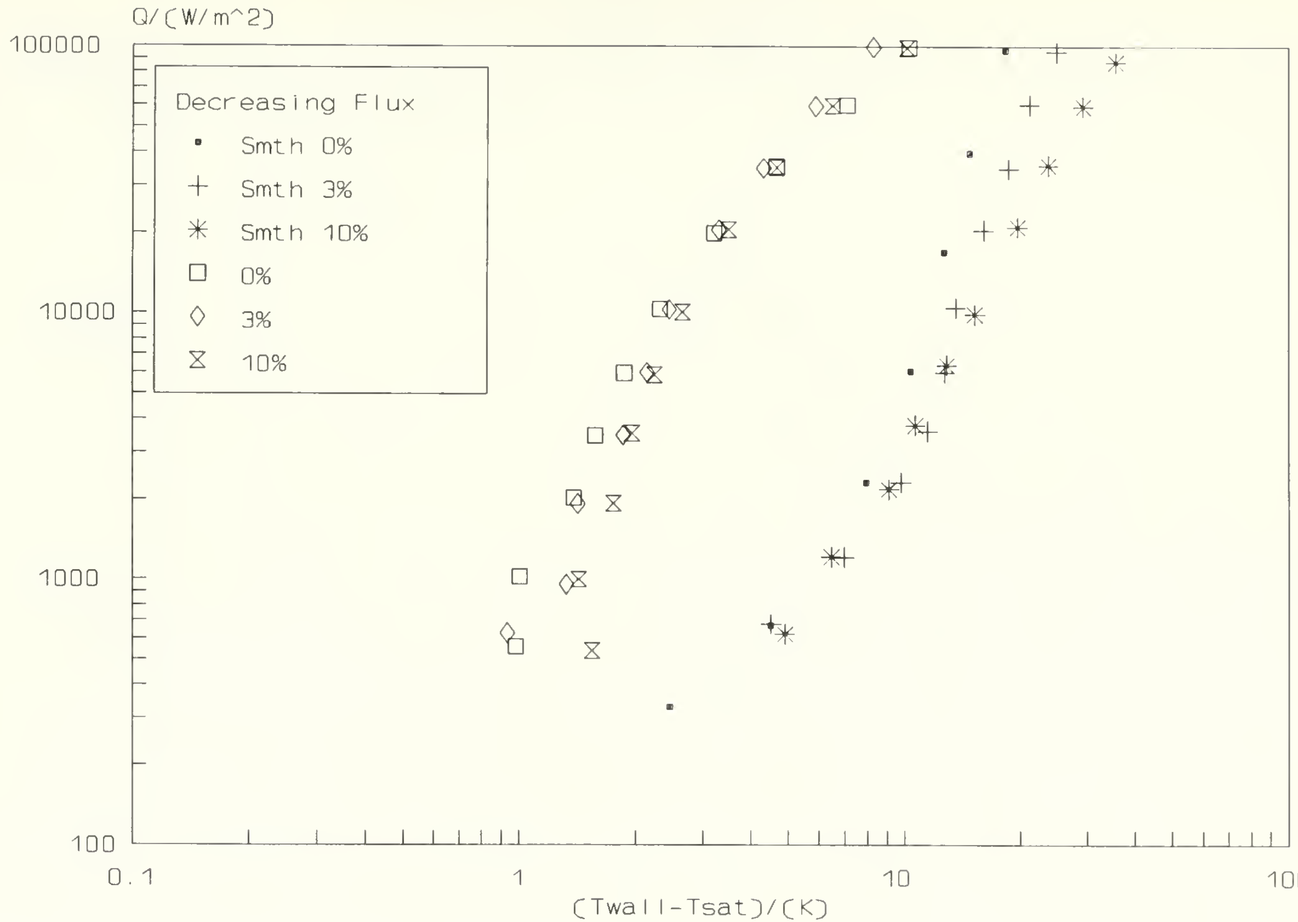


Figure 6.29 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures From GEWA-T 19 fpi Tube

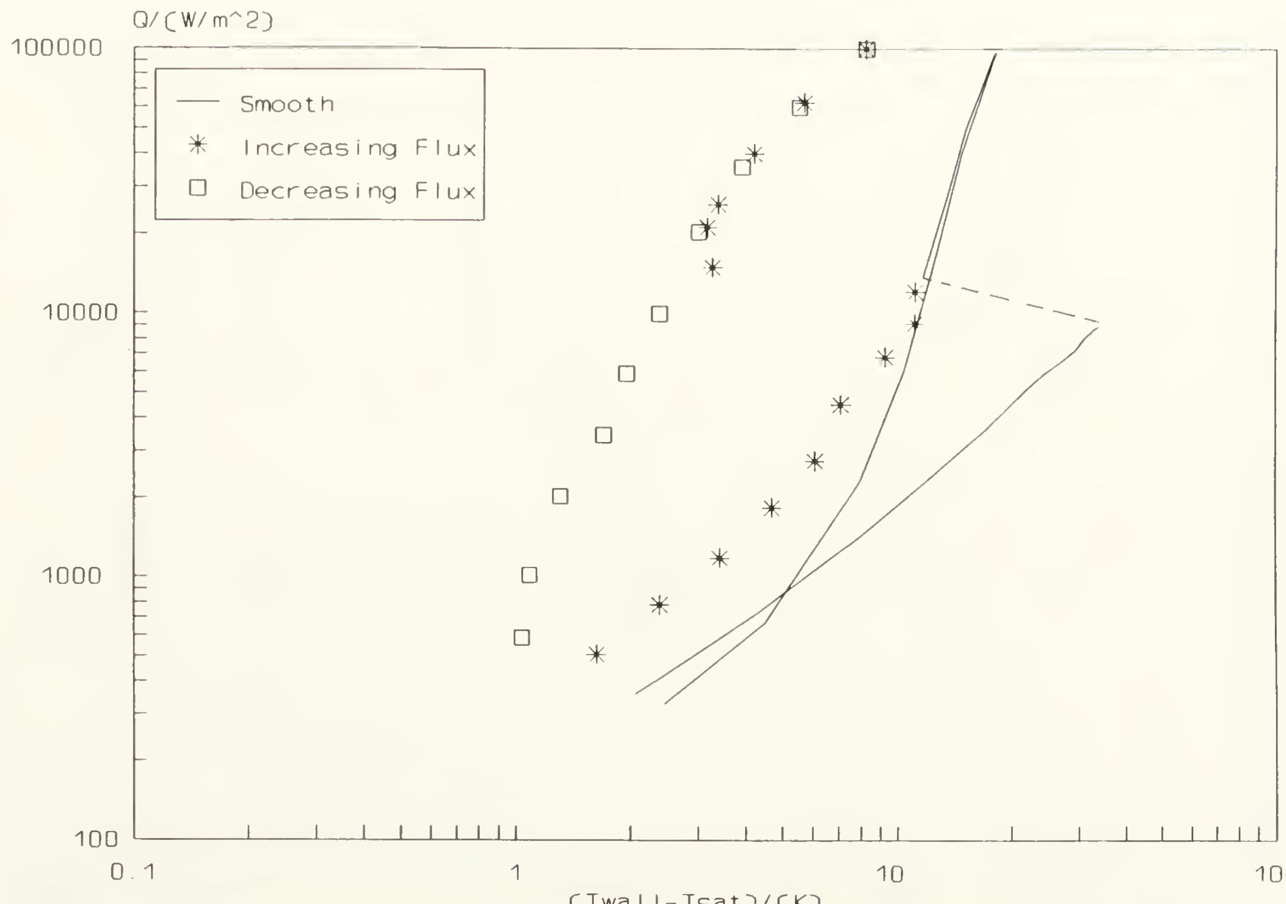


Figure 6.30 Performance Comparison For Pure R-114 Boiling From GEWA-T 26 fpi Tube

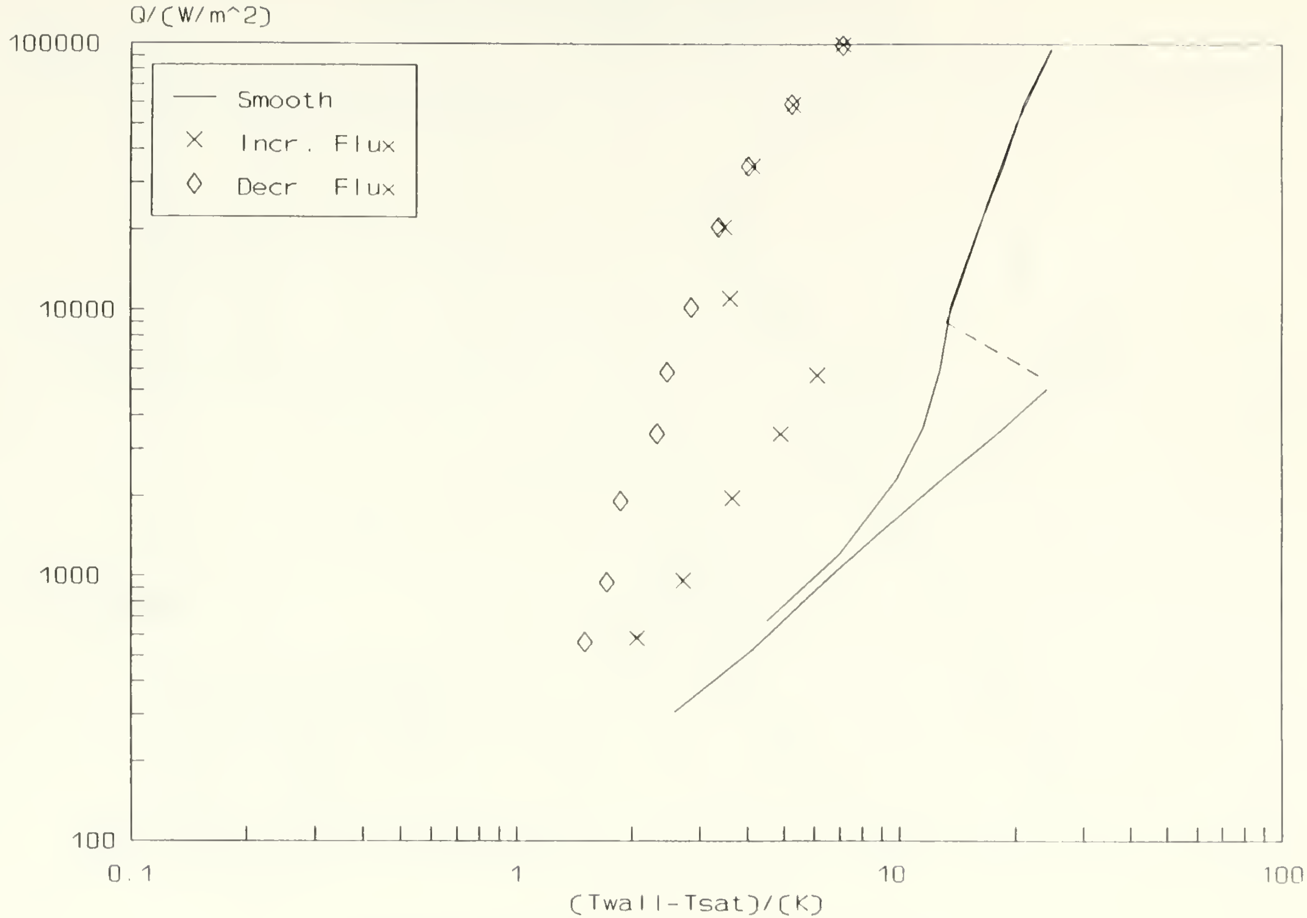


Figure 6.31 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-T 26 fpi Tube

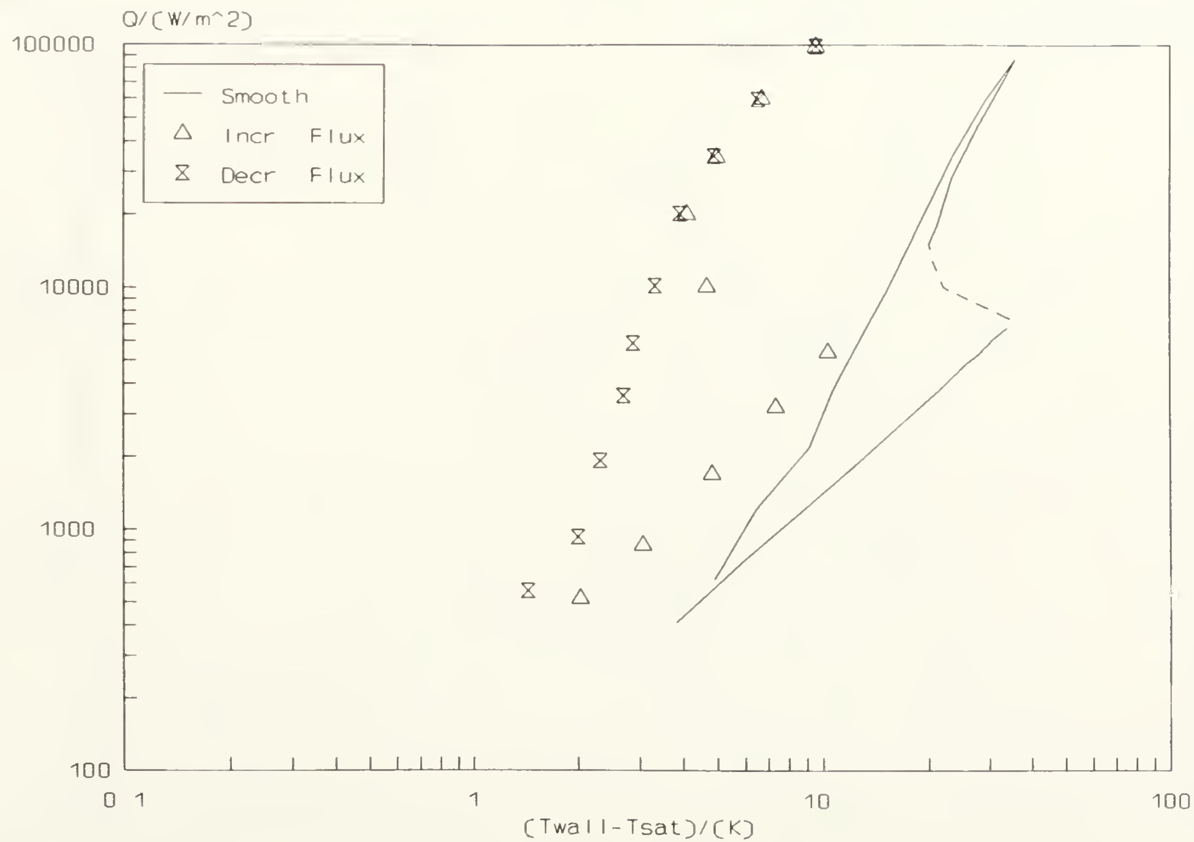


Figure 6 32 Performance Comparison For
Boiling R-114/10% Oil Mixture From
GEWA-T 26 fpi Tube

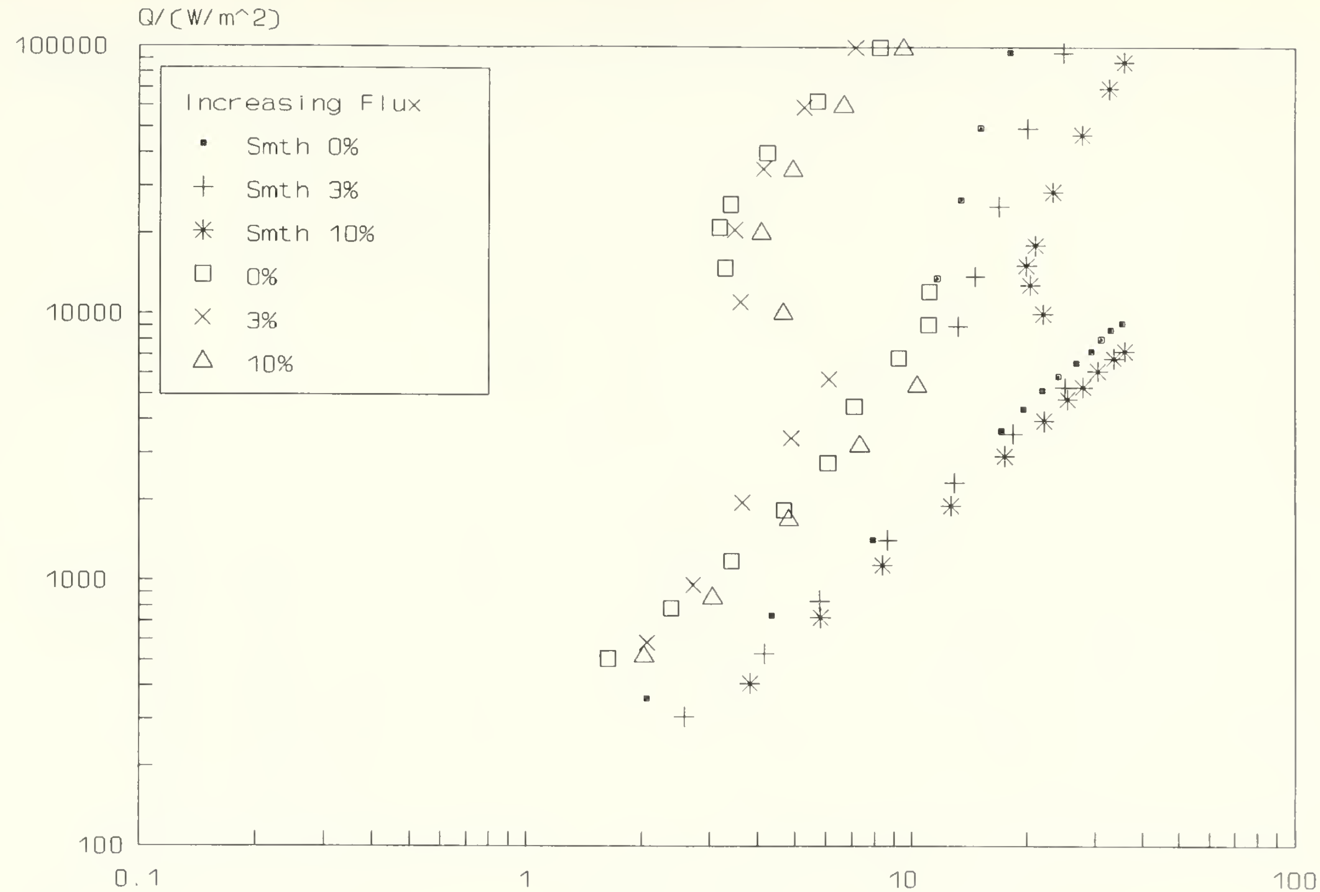


Figure 6.33 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures From GEWA-T 26 fpi Tube

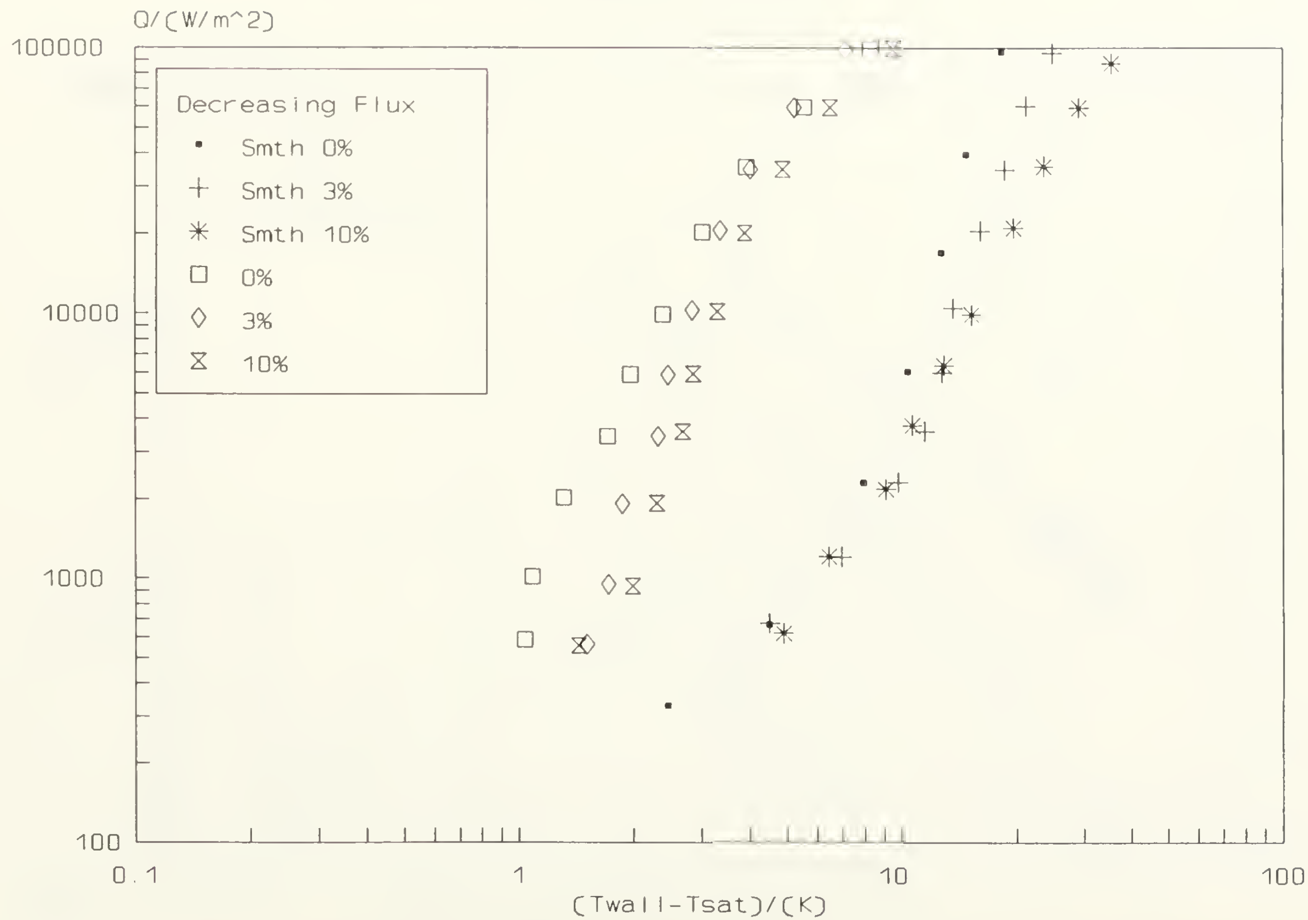


Figure 6.34 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures From GEWA-T 26 fpi Tube

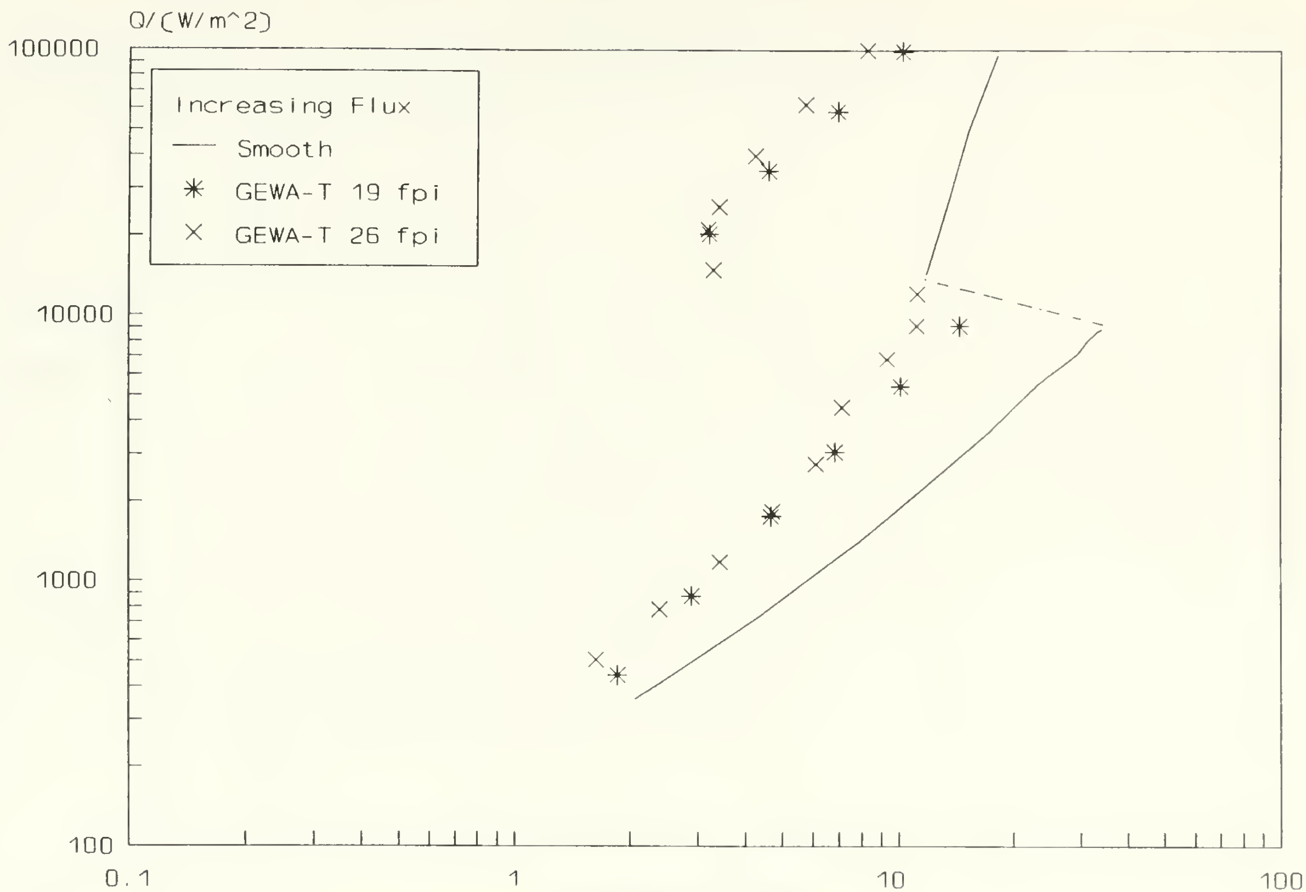


Figure 6.35 Performance Comparison For
Boiling Pure R-114 From
GEWA-T 19/26 fpi Tubes

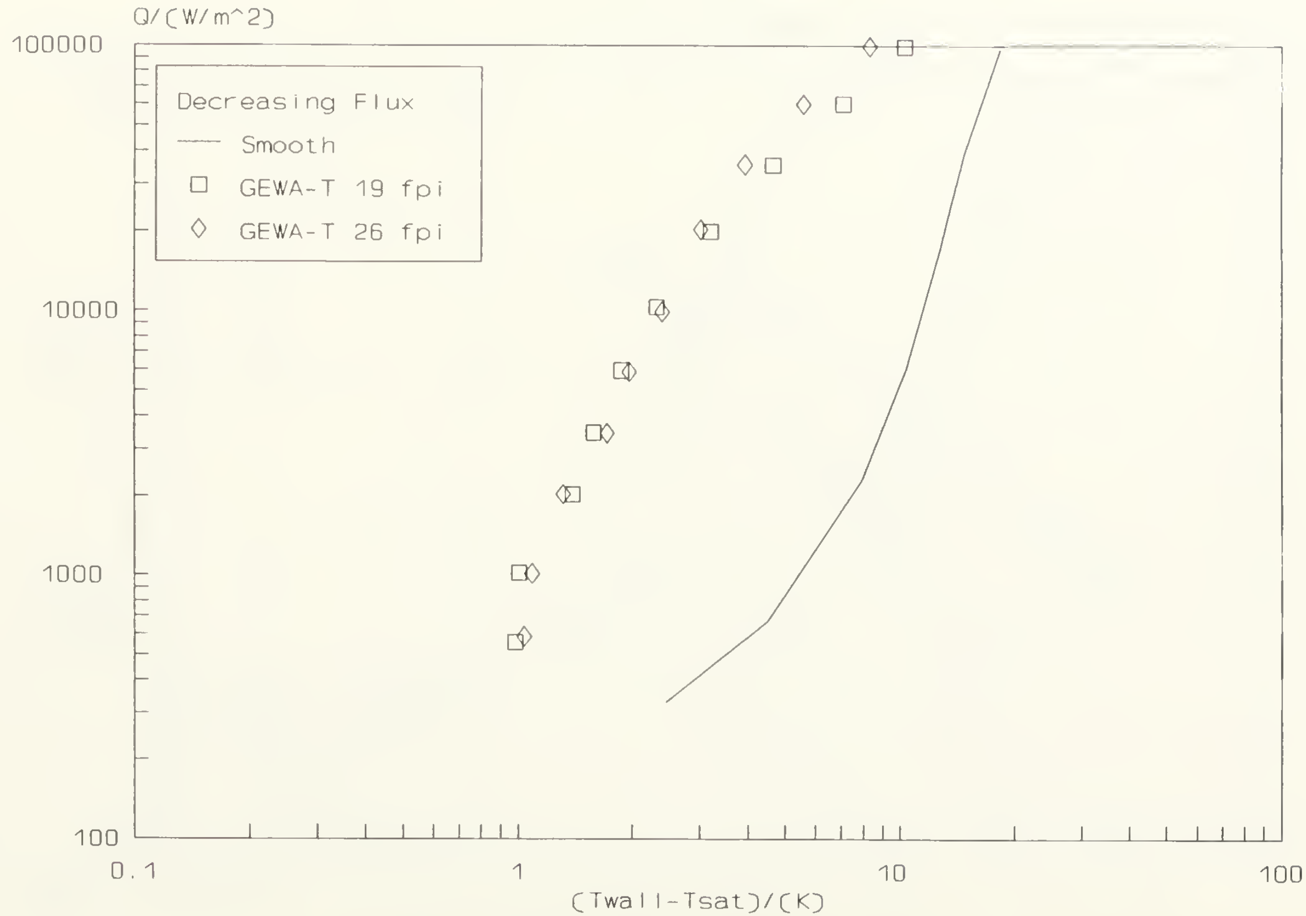


Figure 6.36 Performance Comparison For Boiling Pure R-114 From GEWA-T 19/26 fpi Tubes

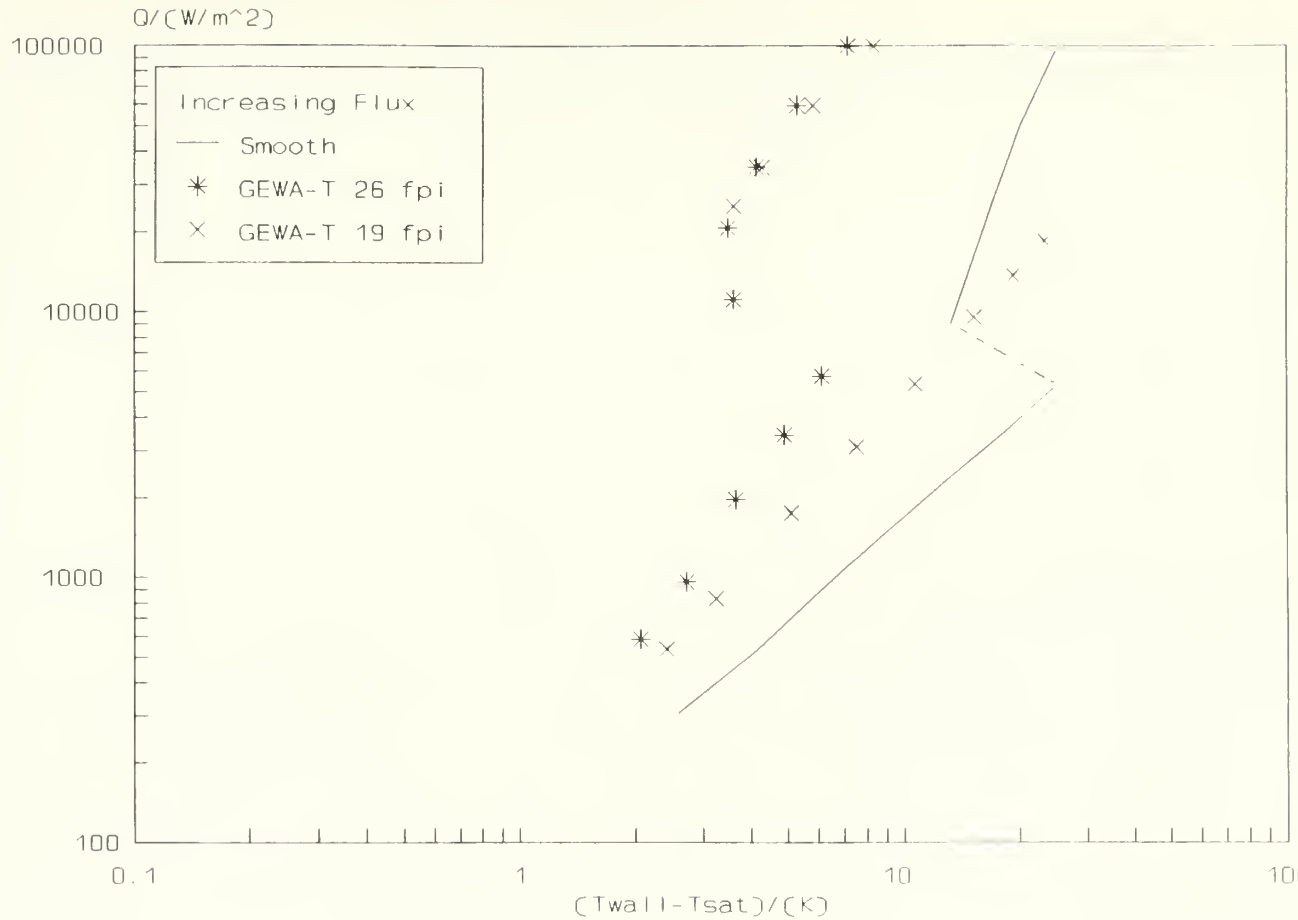


Figure 6.37 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-T 19/26 fpi Tubes

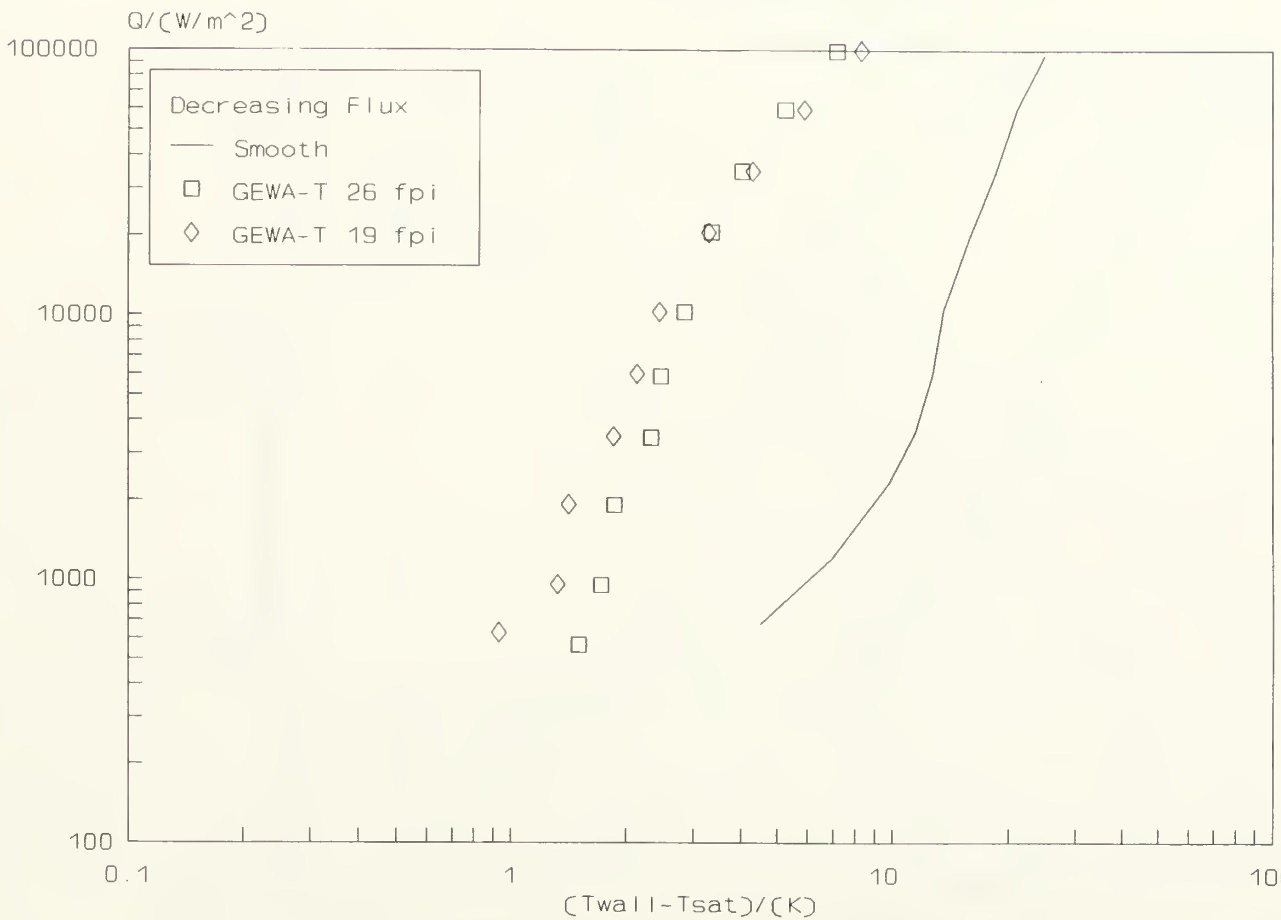


Figure 6.38 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-T 19/26 fpi Tubes

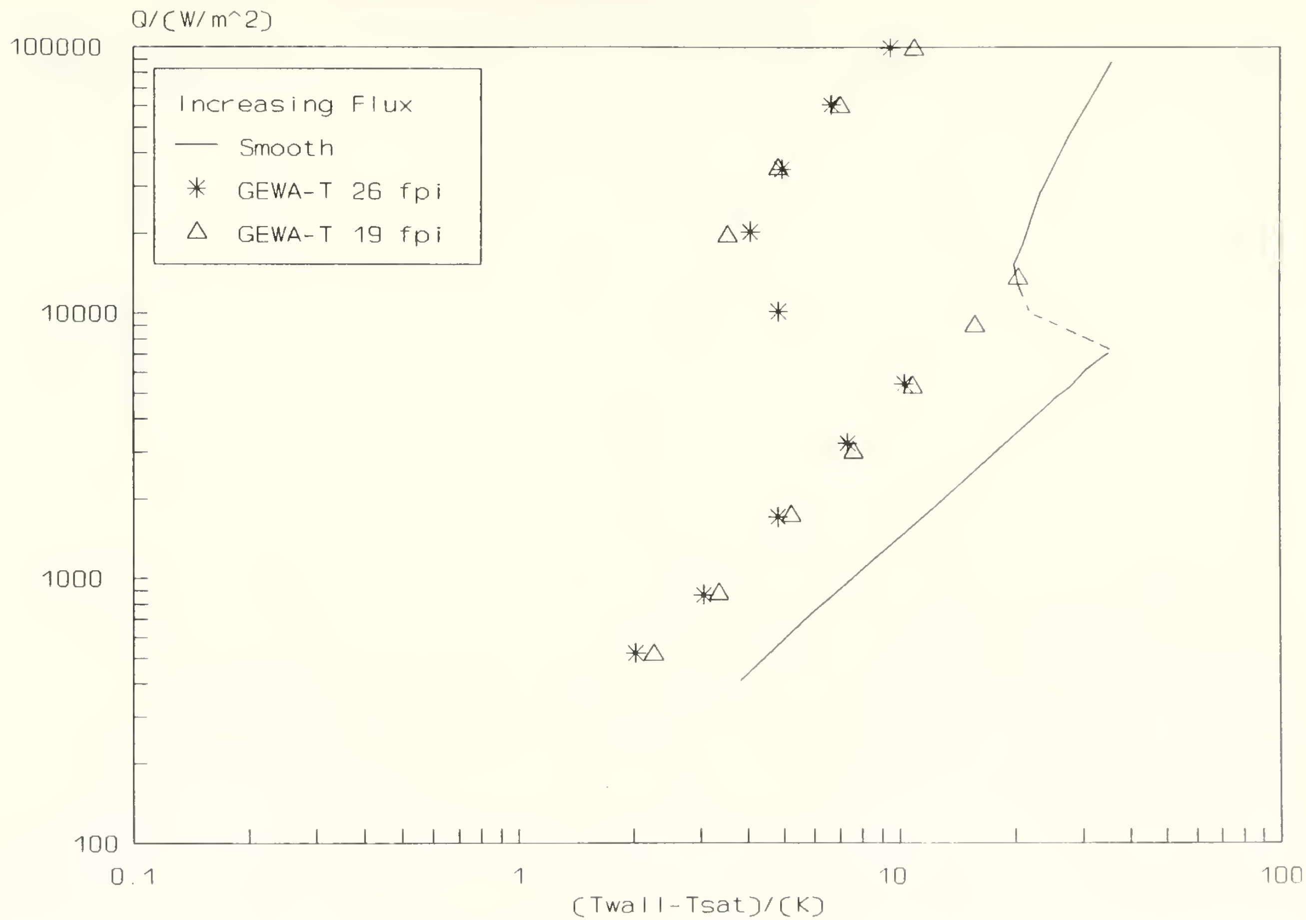


Figure 6.39 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-T 19/26 fpi Tubes

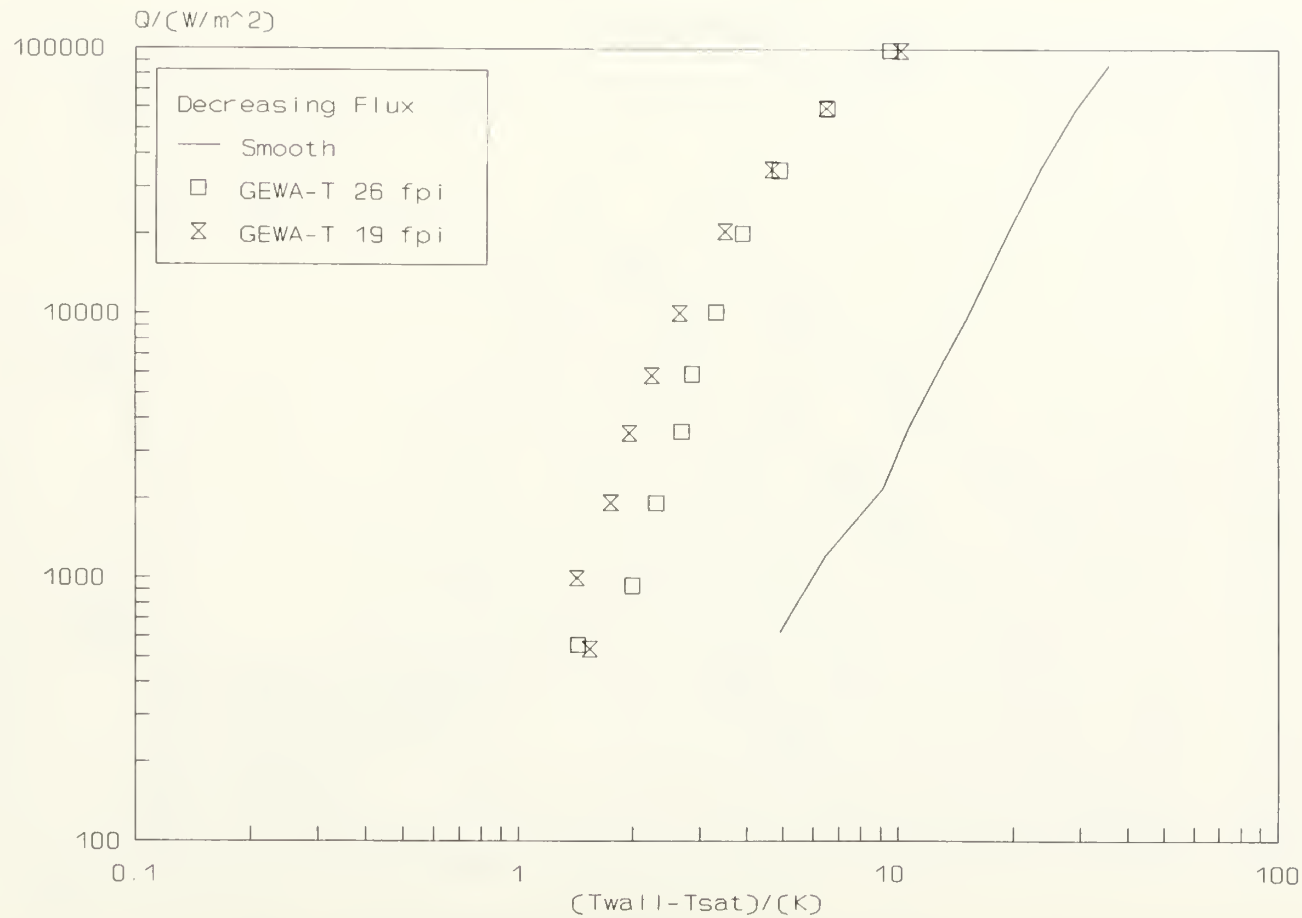


Figure 6.40 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-T 19/26 fpi Tubes

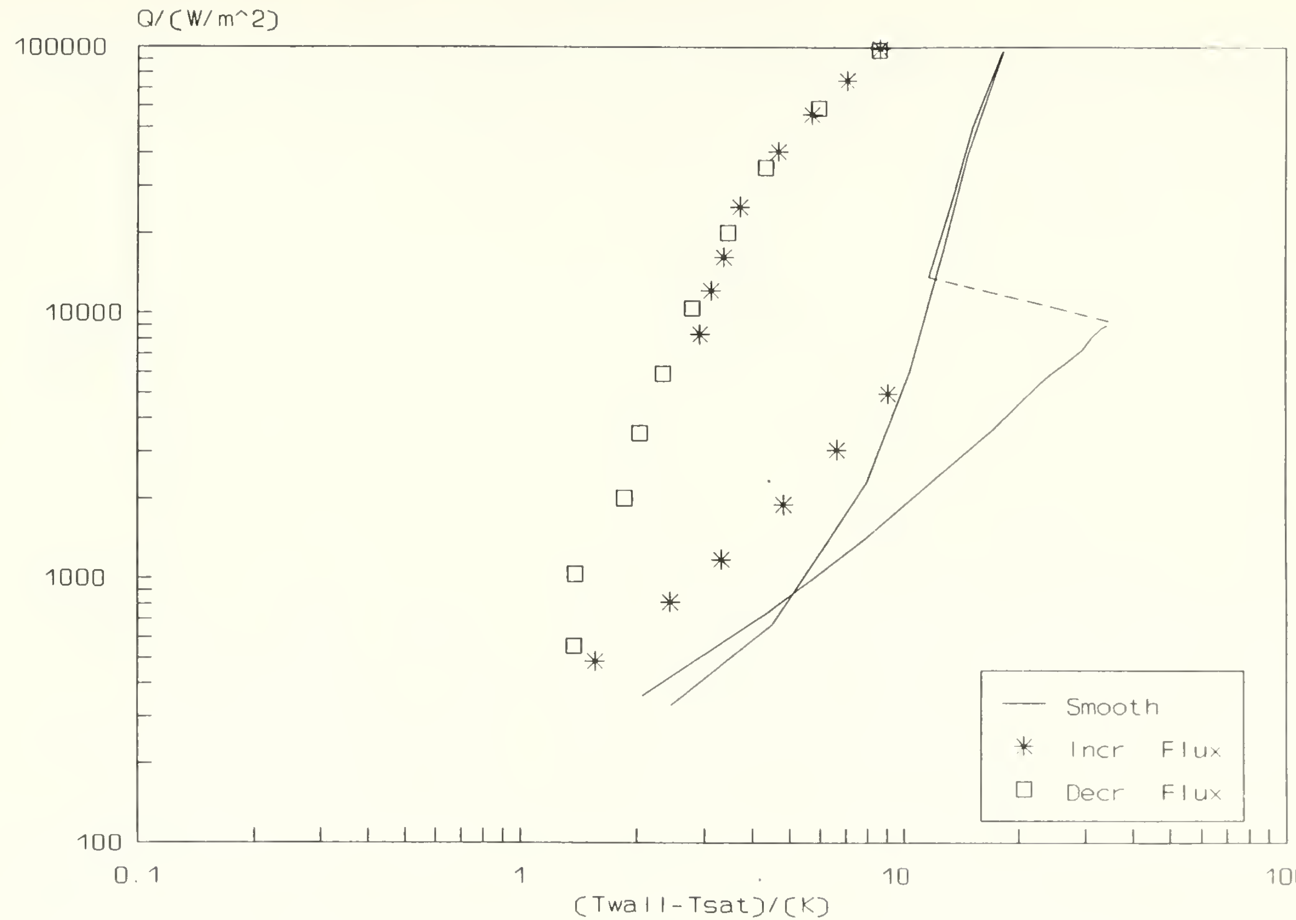


Figure 6.41 Performance Comparison For
Boiling Pure R-114 From
GEWA-YX 26 fpi Tube

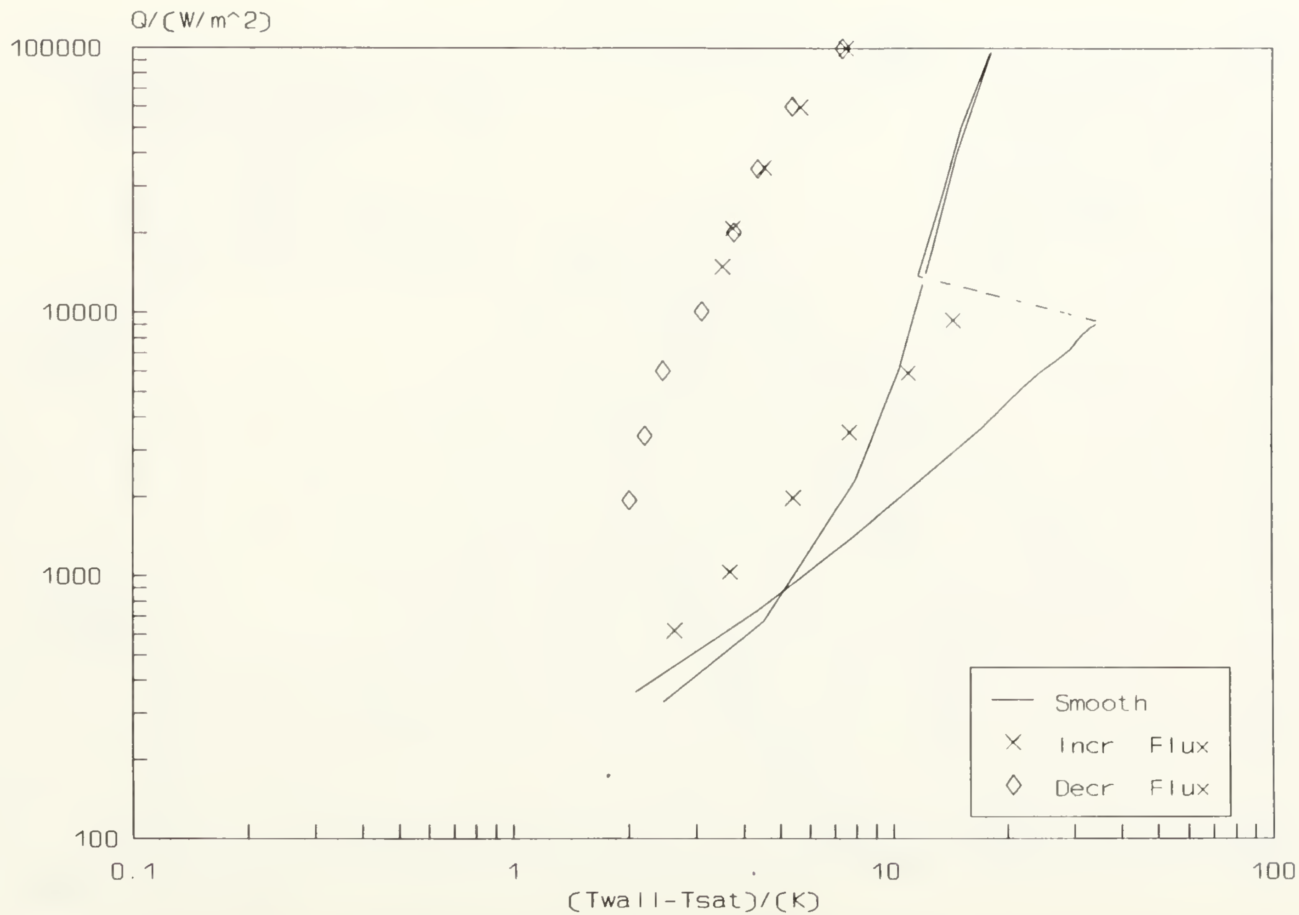


Figure 6.42 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-YX 26 fpi Tube

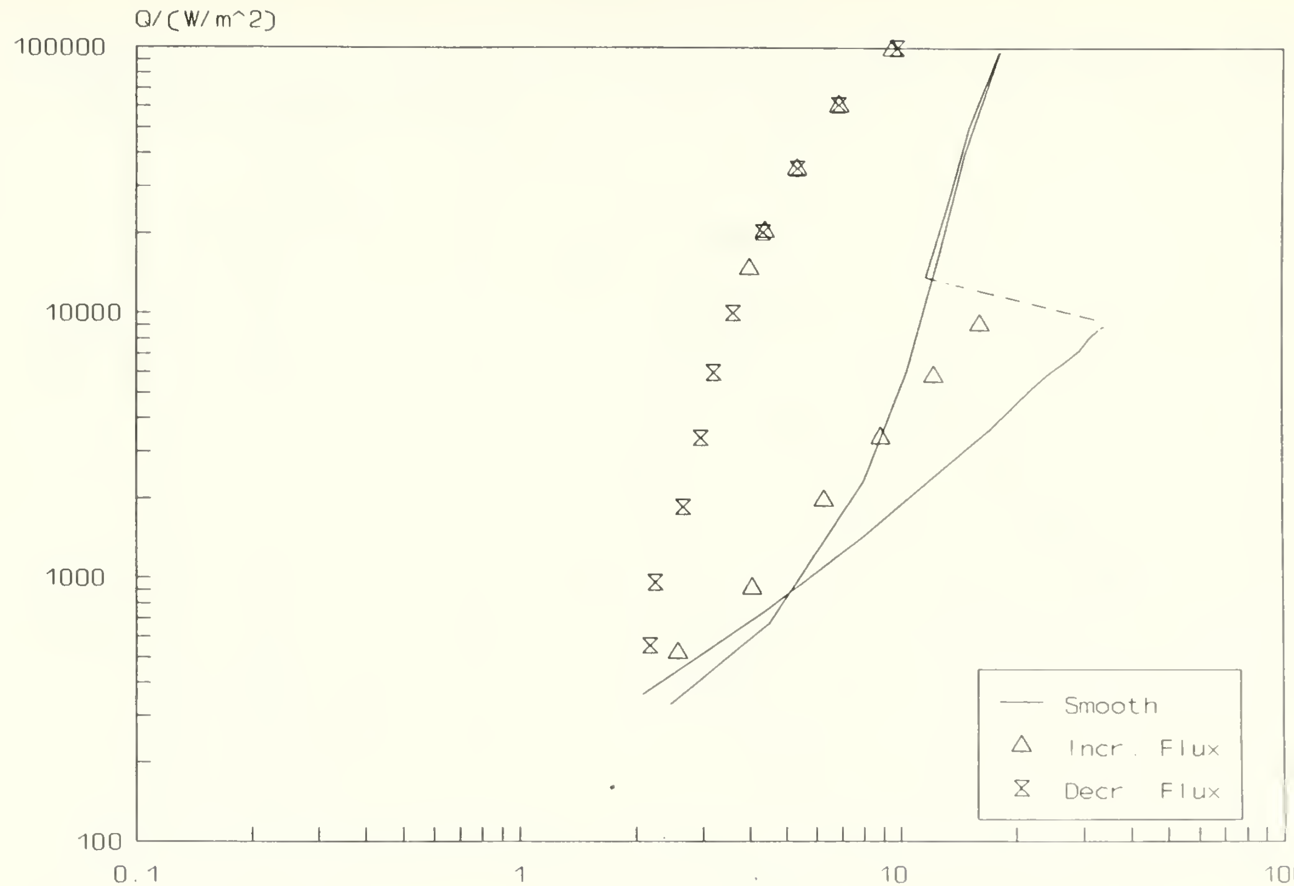


Figure 6.43 Performance Comparison For
Boiling R-114/10% Oil Mixture From
GEWA-YX 26 fpi Tube

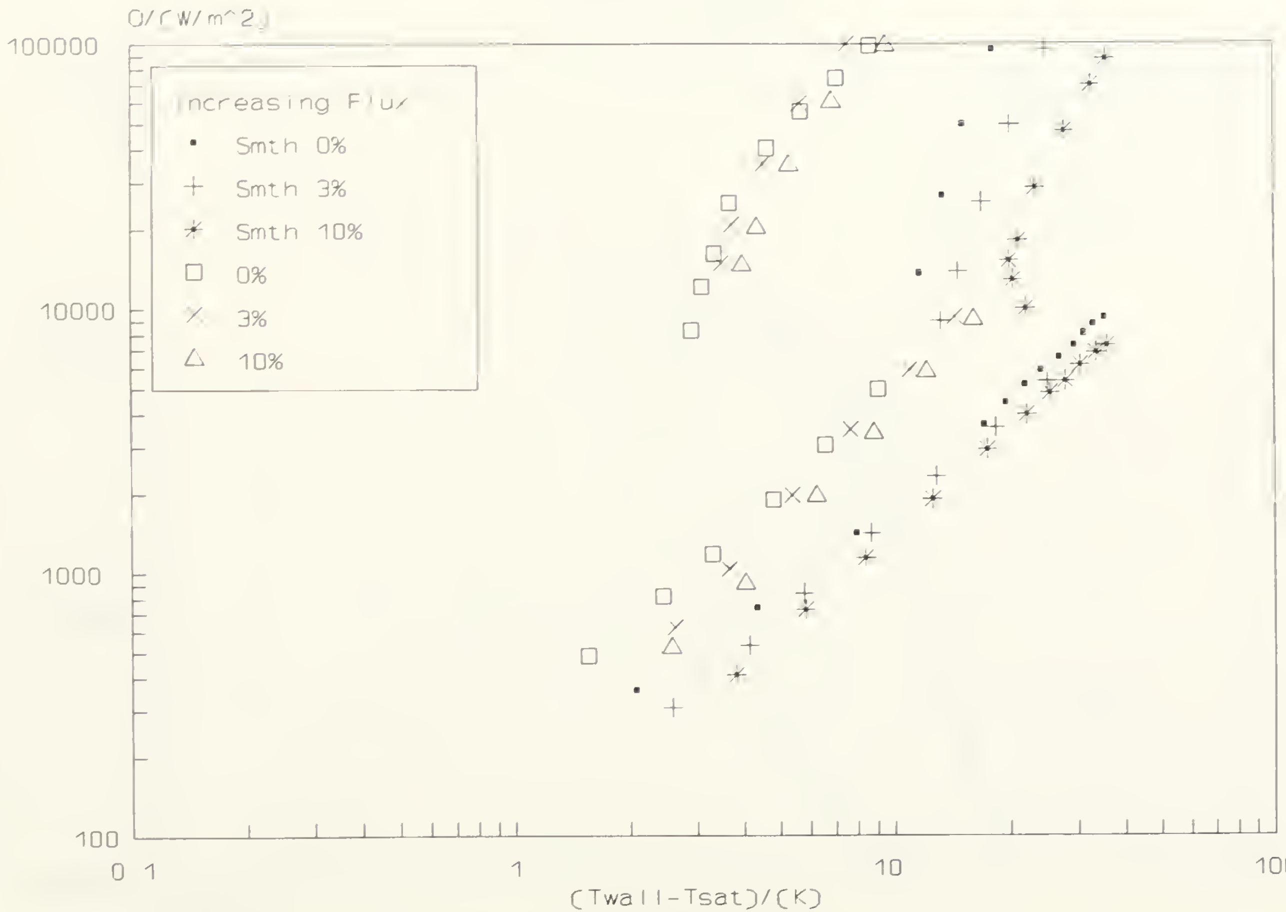


Figure 6.44 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures From GEWA-YX 26 fpi Tube

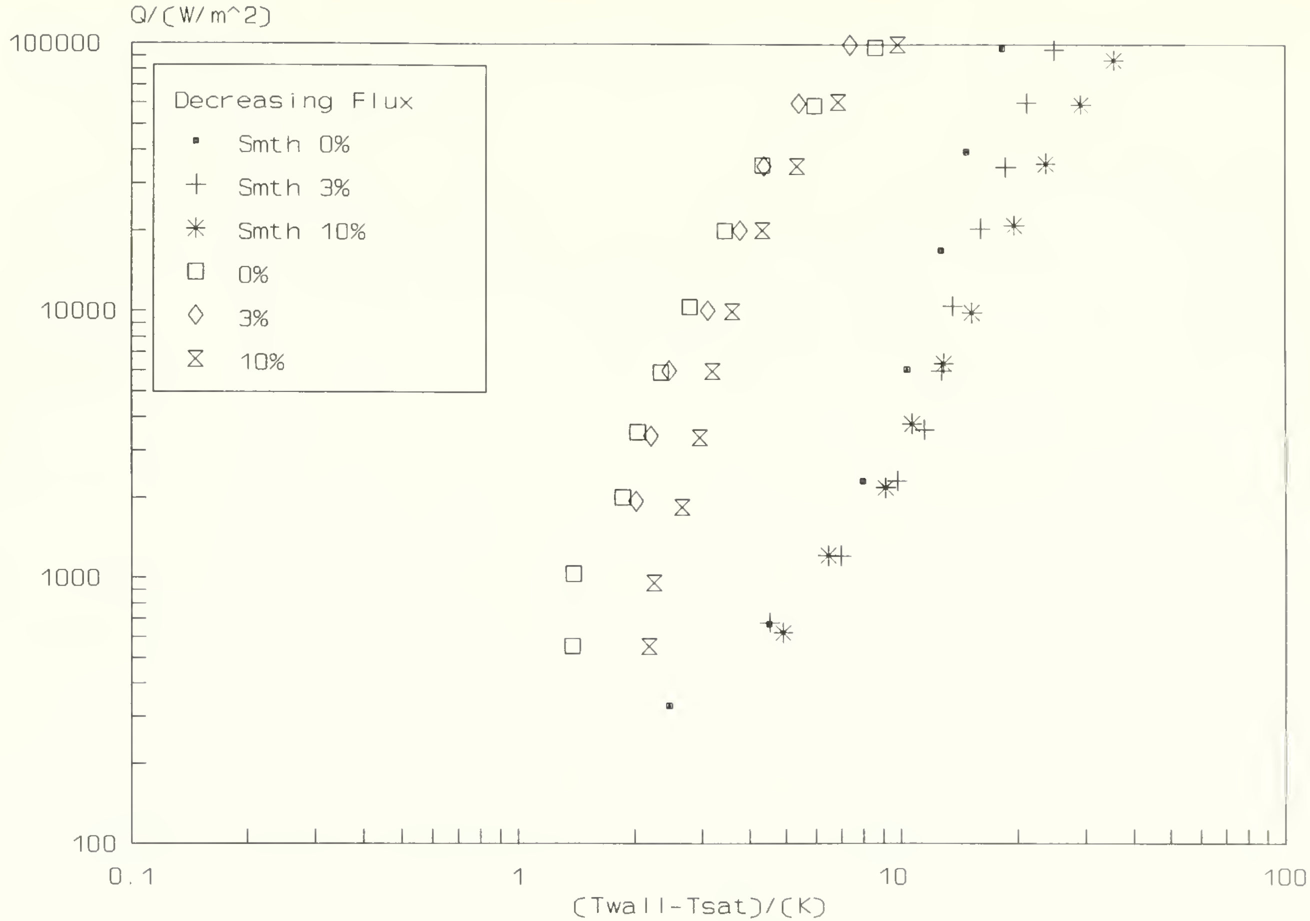


Figure 6.45 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures From GEWA-YX 26 fpi Tube

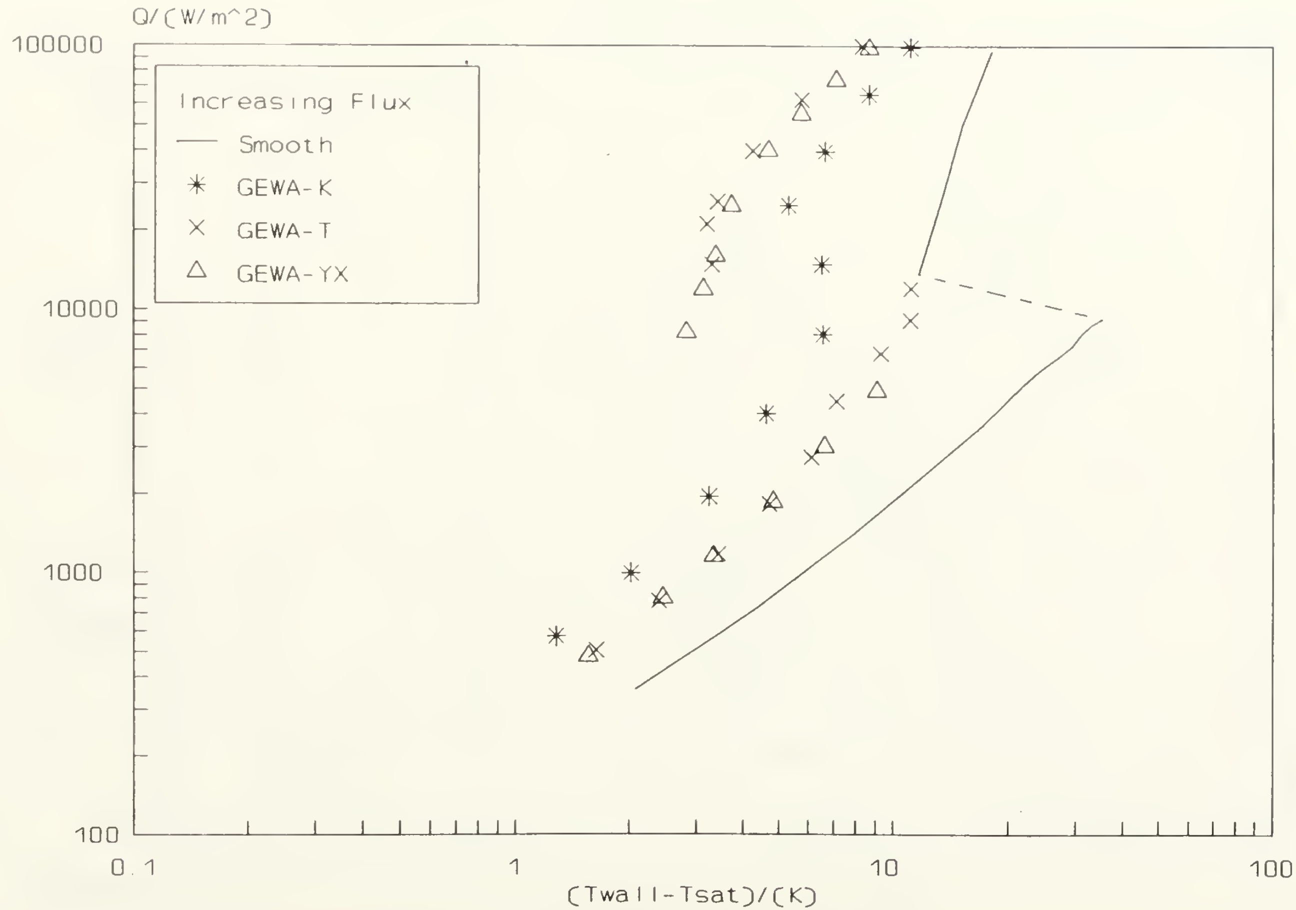


Figure 6.46 Performance Comparison For
Pure R-114 Boiling From
GEWA-K\T\YX 26 fpi Tubes

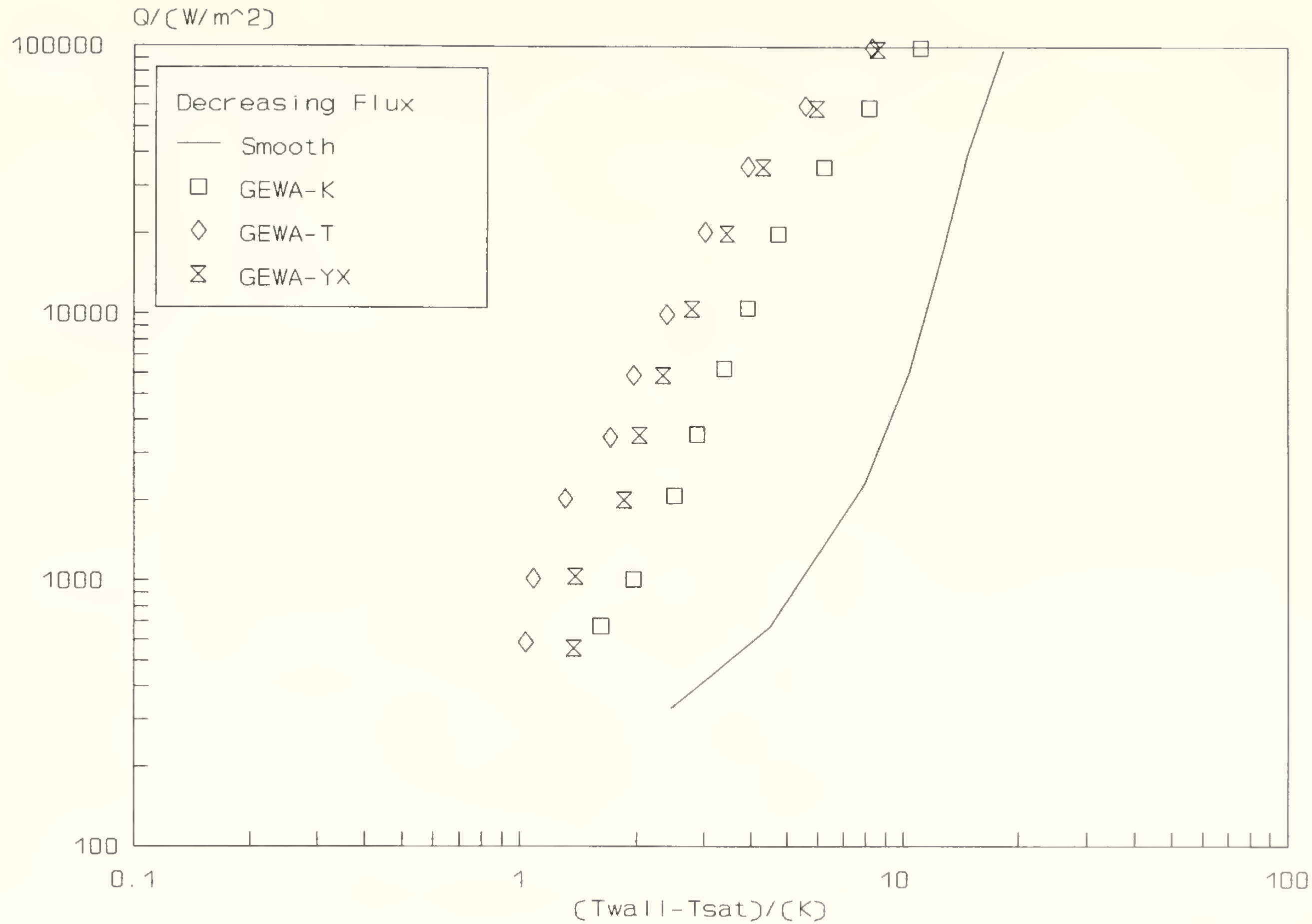


Figure 6.47 Performance Comparison For Boiling Pure R-114 From GEWA-K/T/YX 26 fpi Tubes

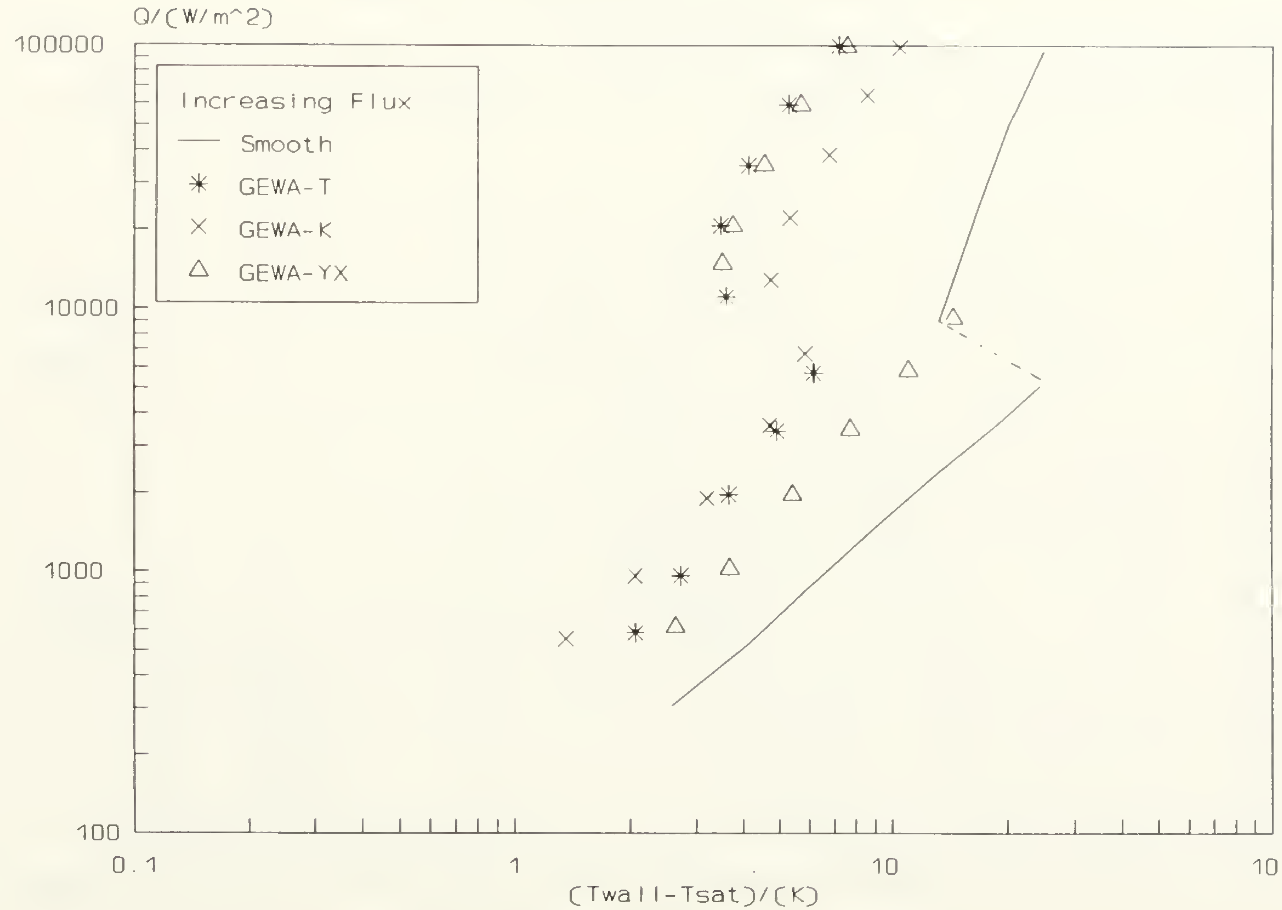


Figure 6.48 Performance Comparison For
Boiling R-114/3% Oil Mixture From
GEWA-K/T/YX 26 fpi Tubes

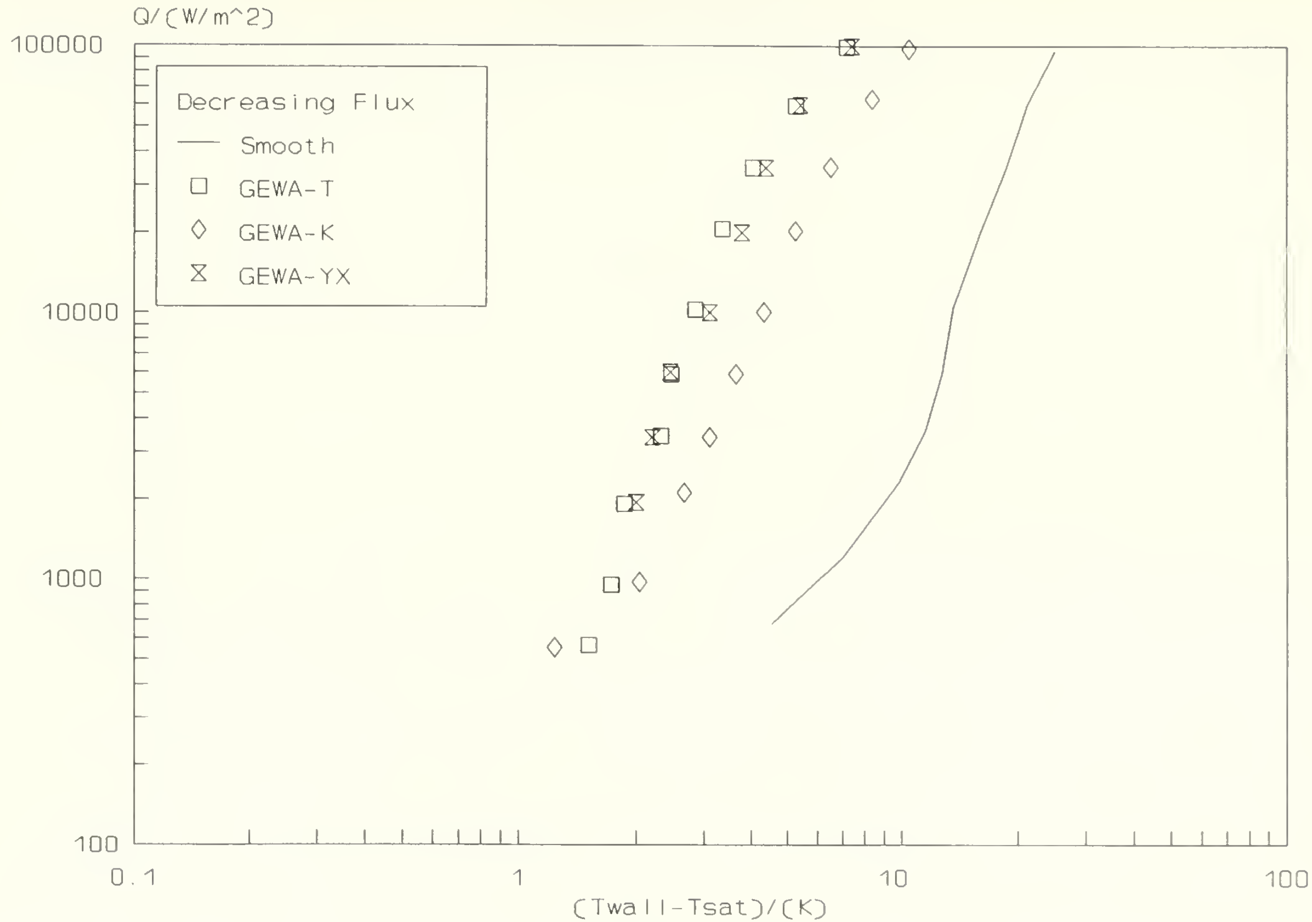


Figure 6.49 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-K/T/YX 26 fpi Tubes

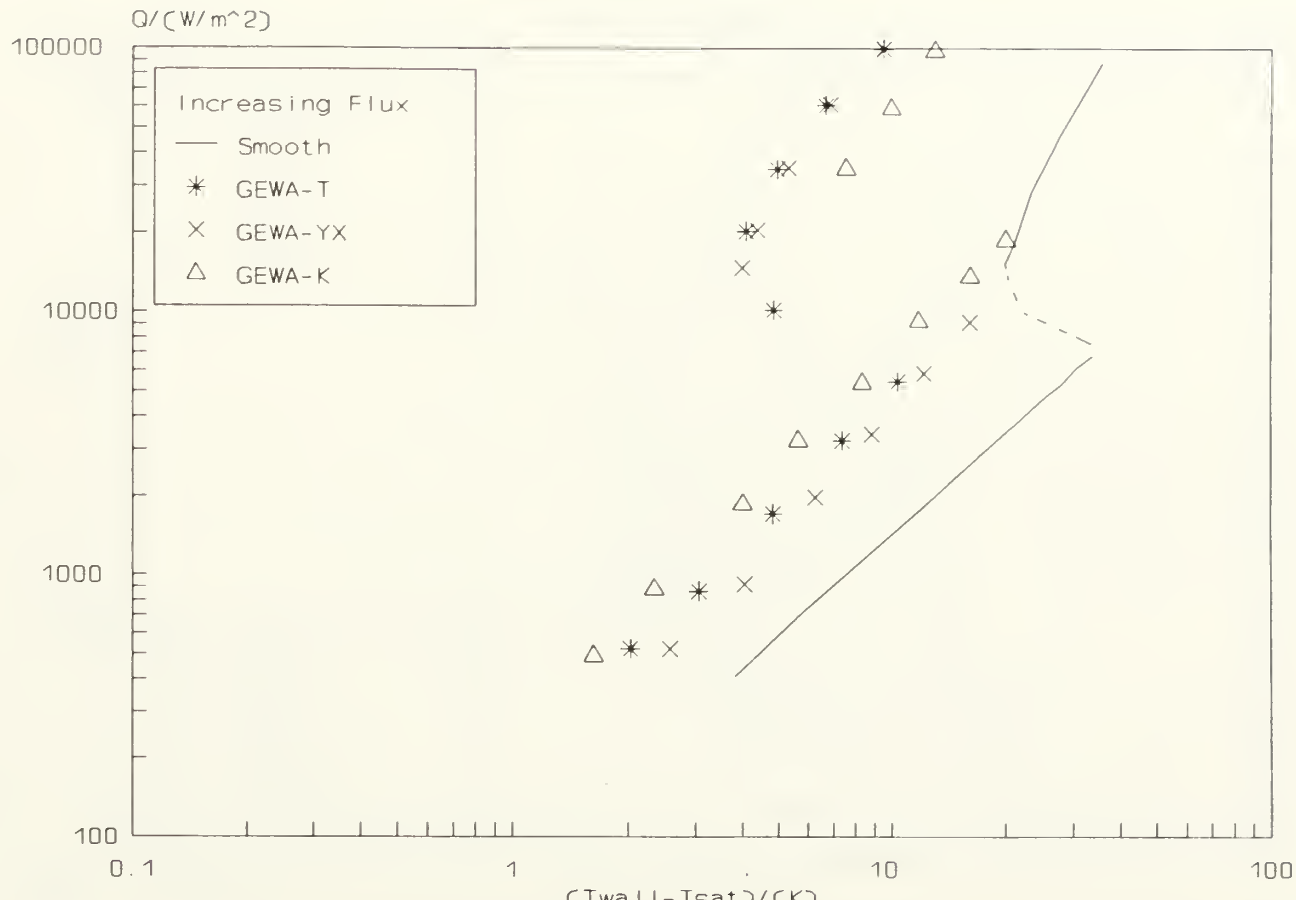


Figure 6.50 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-K/T/YX 26 fpi Tubes

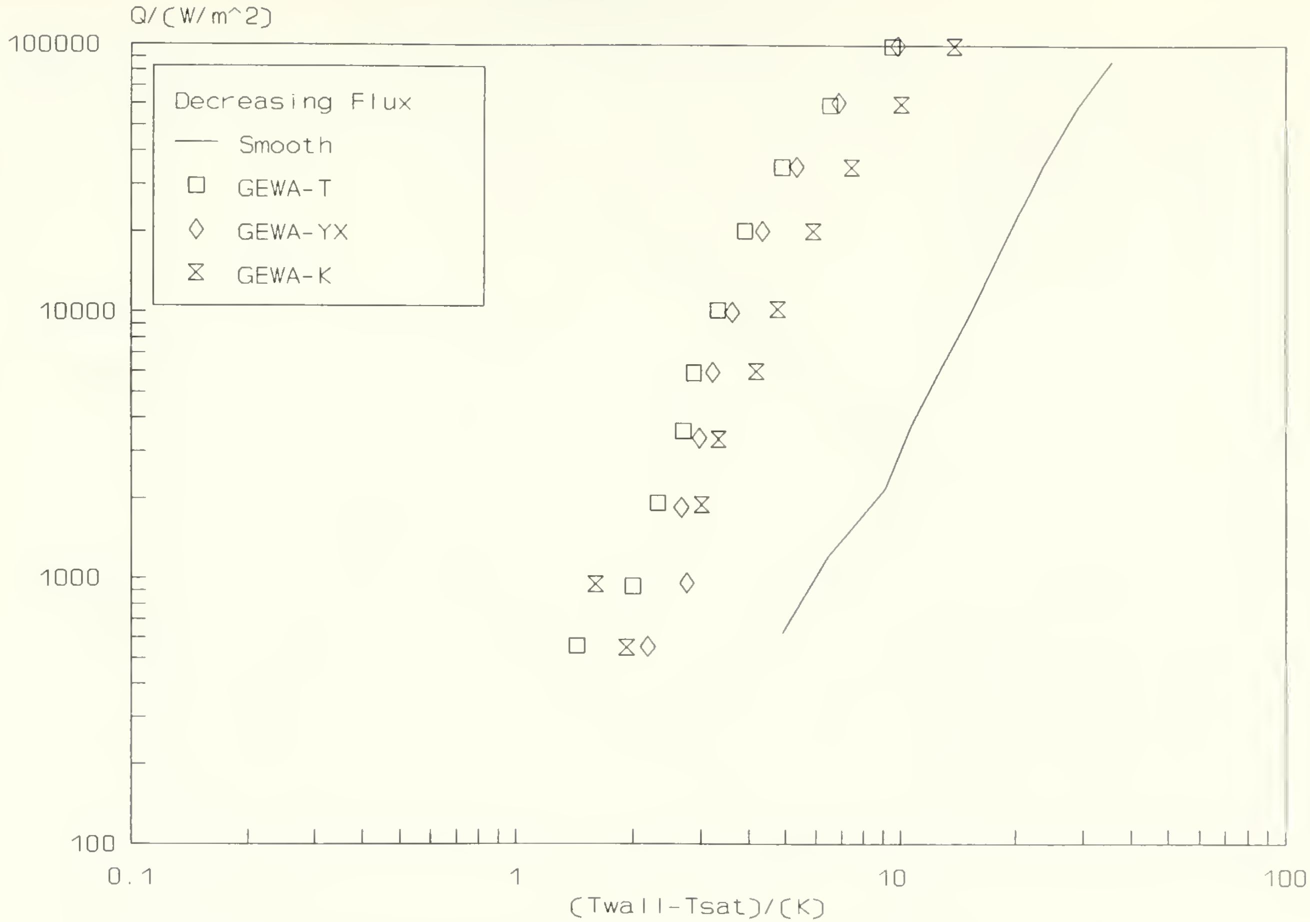


Figure 6.51 Performance Comparison For Boiling R-114/10% Oil Mixture From GEWA-K/T/YX 26 fpi

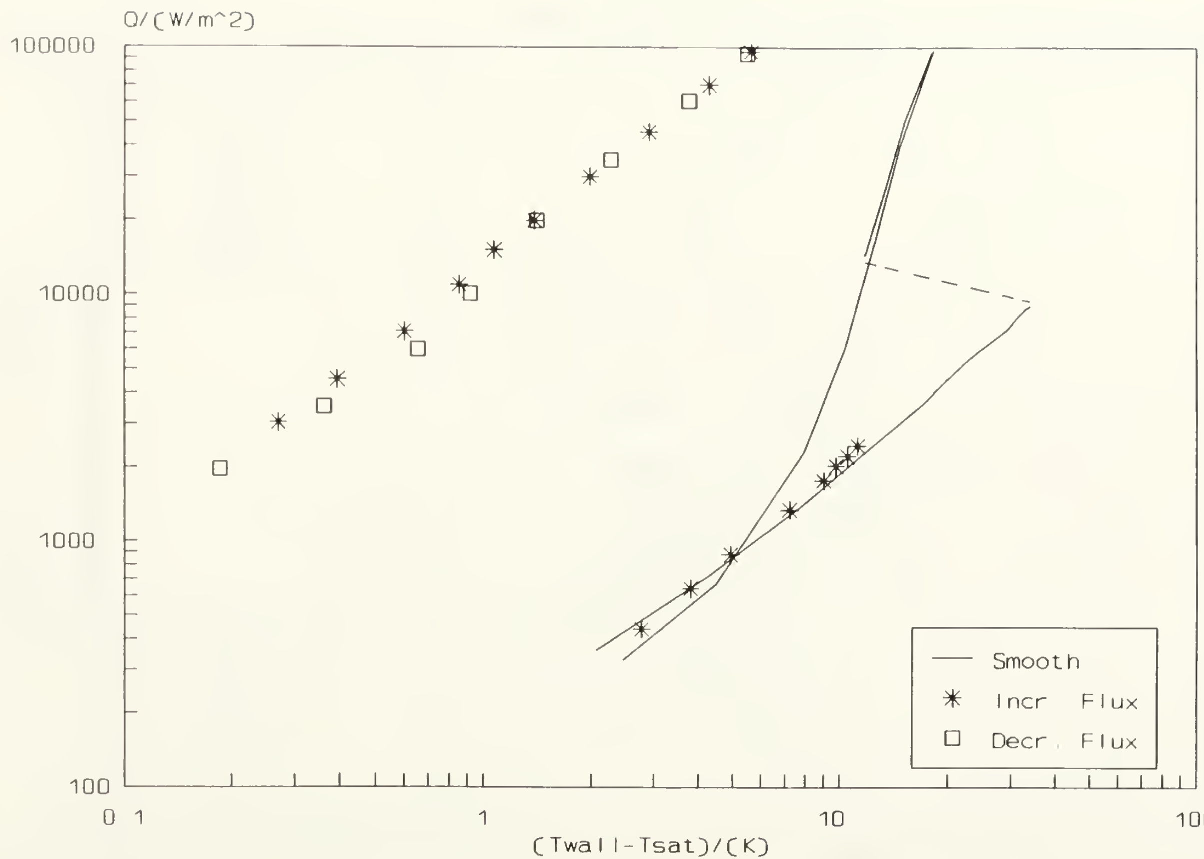


Figure 6.52 Performance Comparison for Pure R-114 Boiling from High Flux Tube

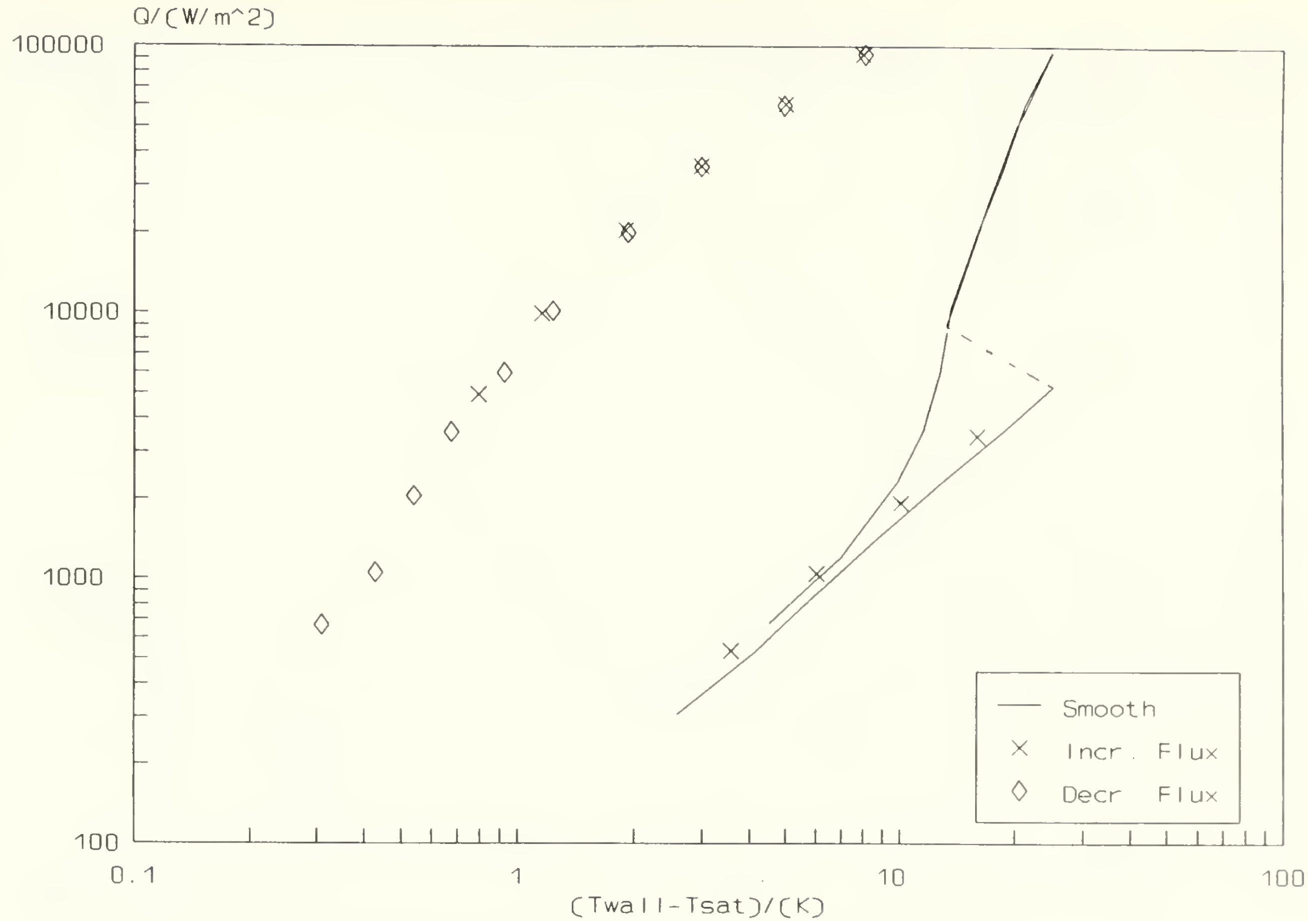


Figure 6.53 Performance Comparison For Boiling R-114/3% Oil Mixture From High Flux Tube

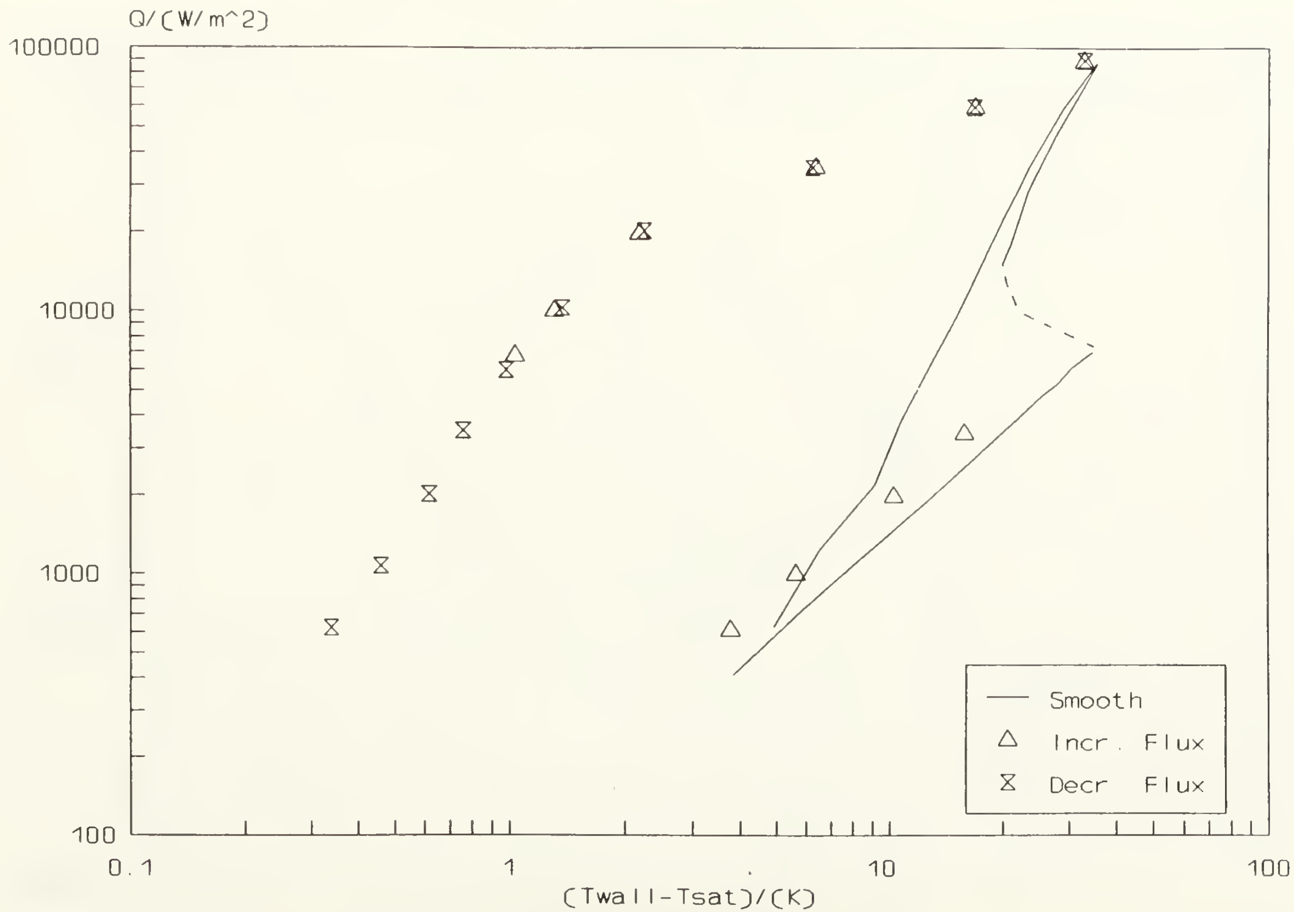


Figure 6.54 Performance Comparison For Boiling R-114/10% Oil Mixture From High Flux Tube

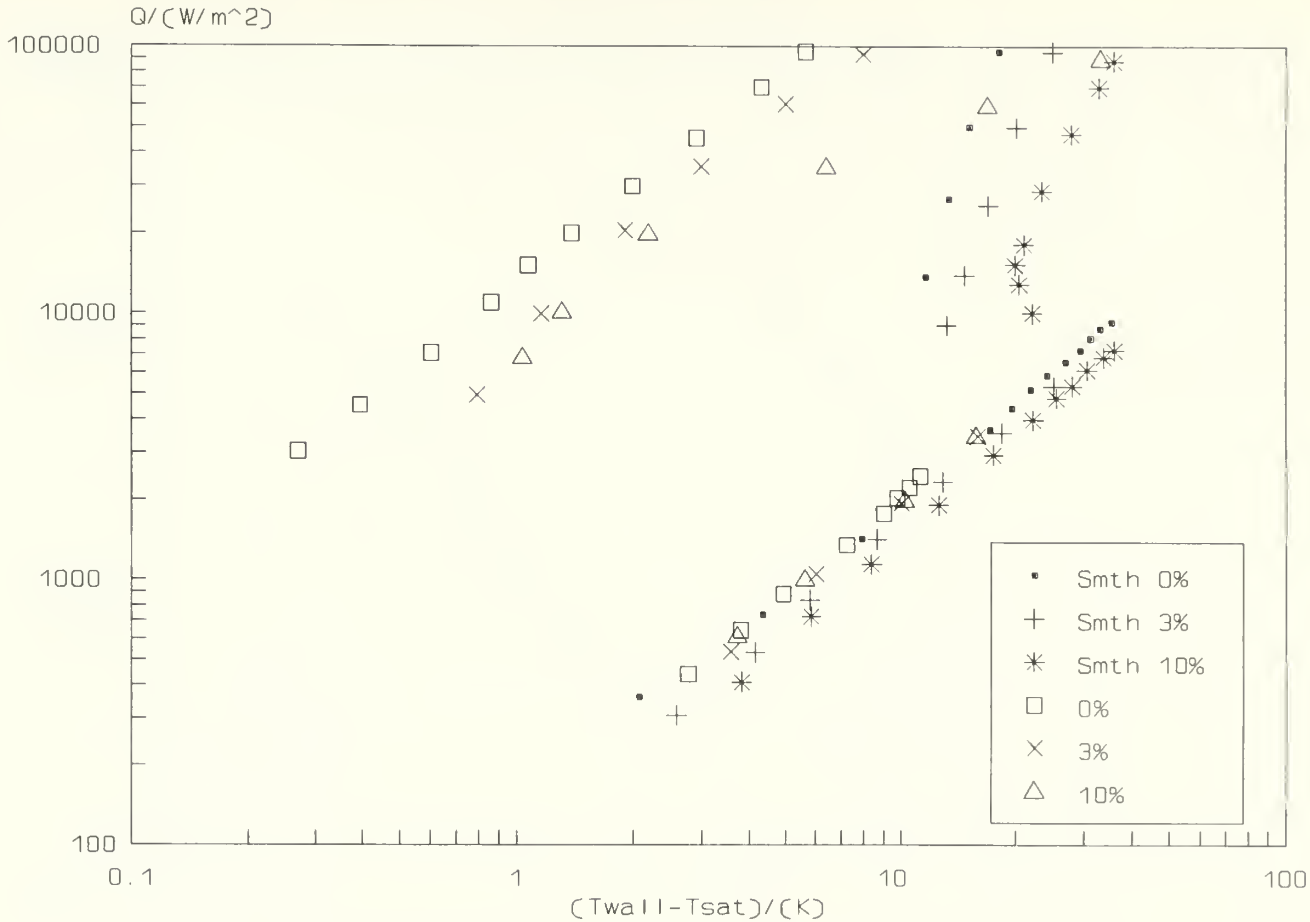


Figure 6.55 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures Increasing Flux From High Flux Tube

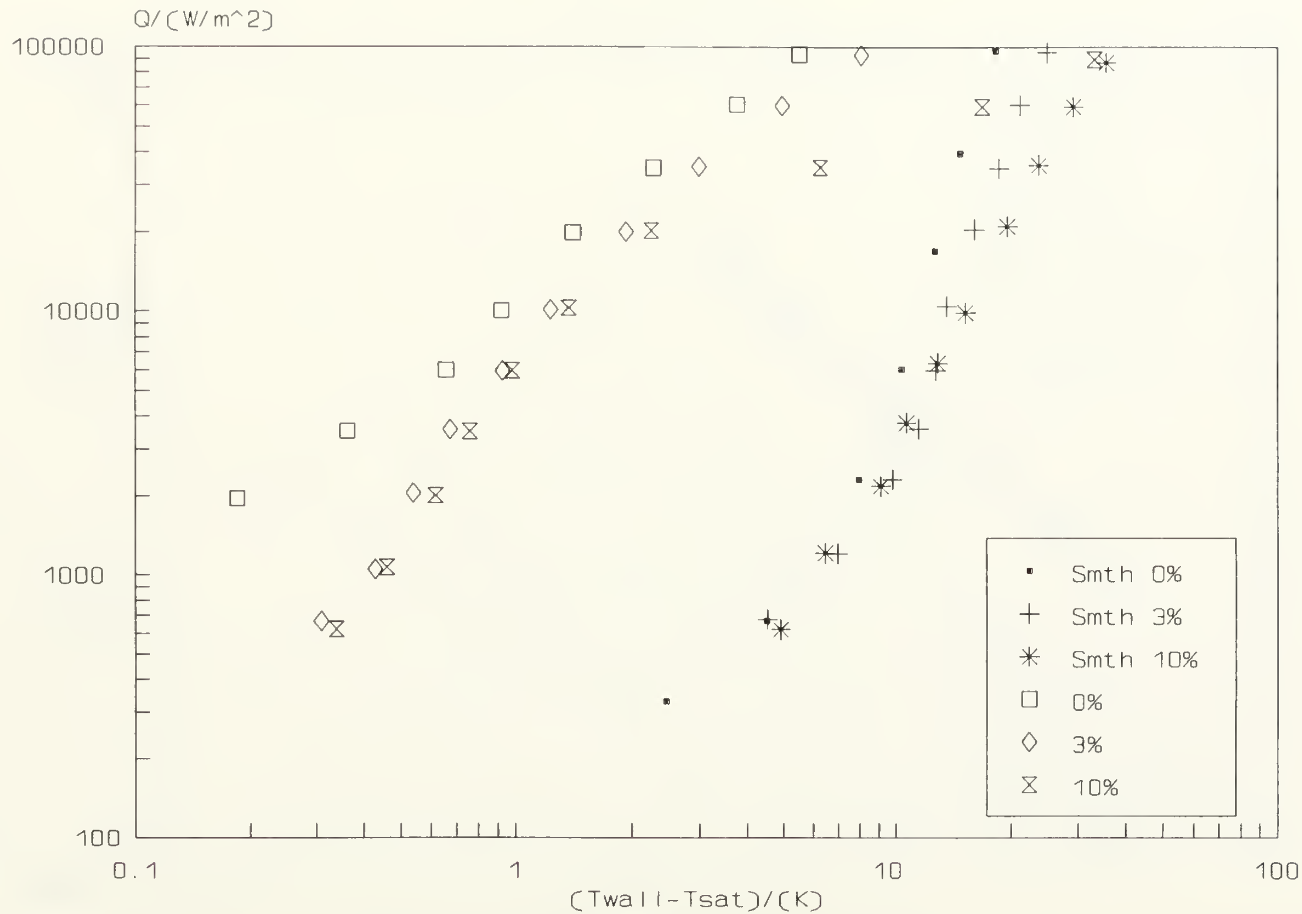


Figure 6.56 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures Decreasing Flux From High Flux Tube

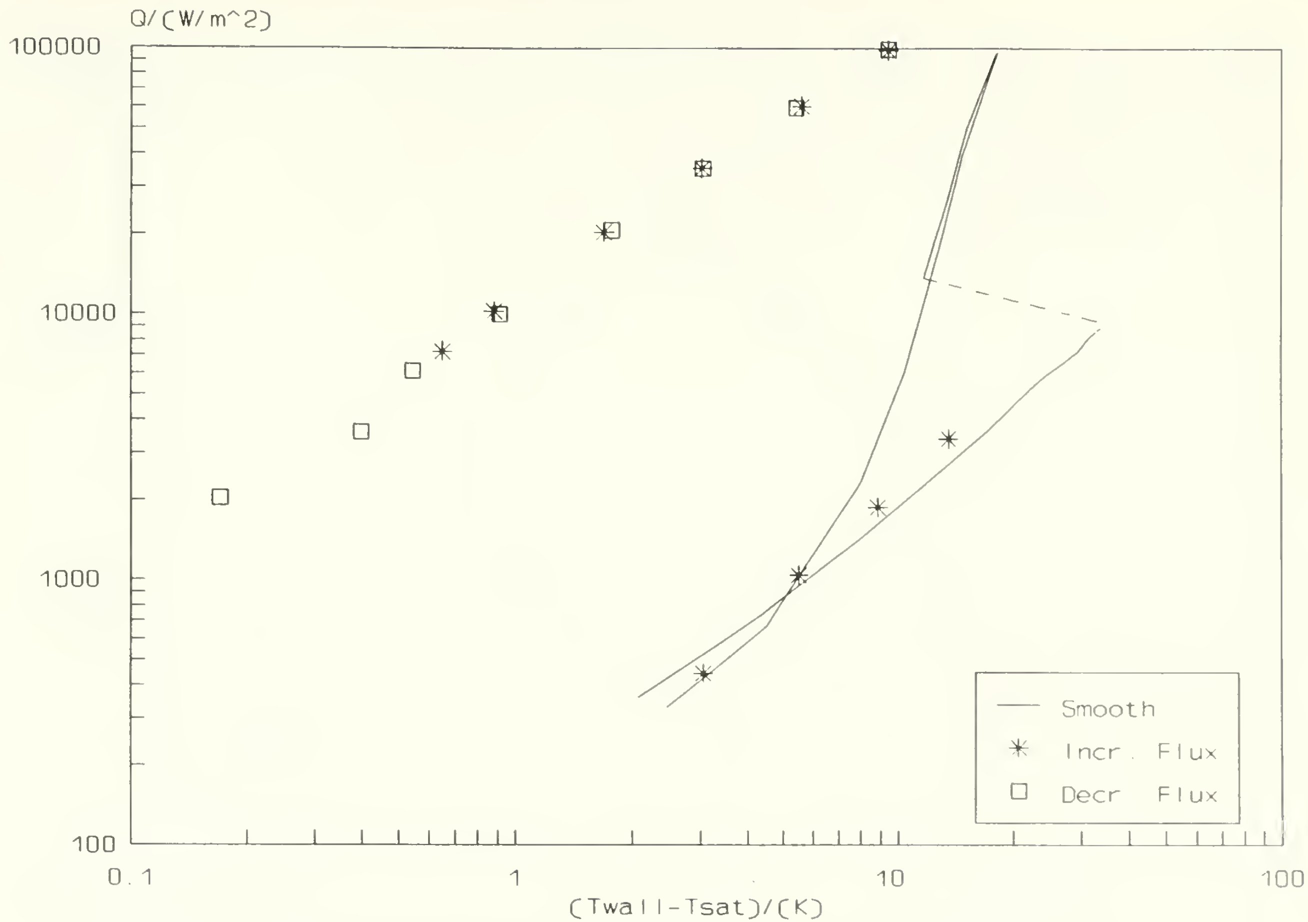


Figure 6.57 Performance Comparison For Pure R-114 Boiling From Thermoexcel-E Tube

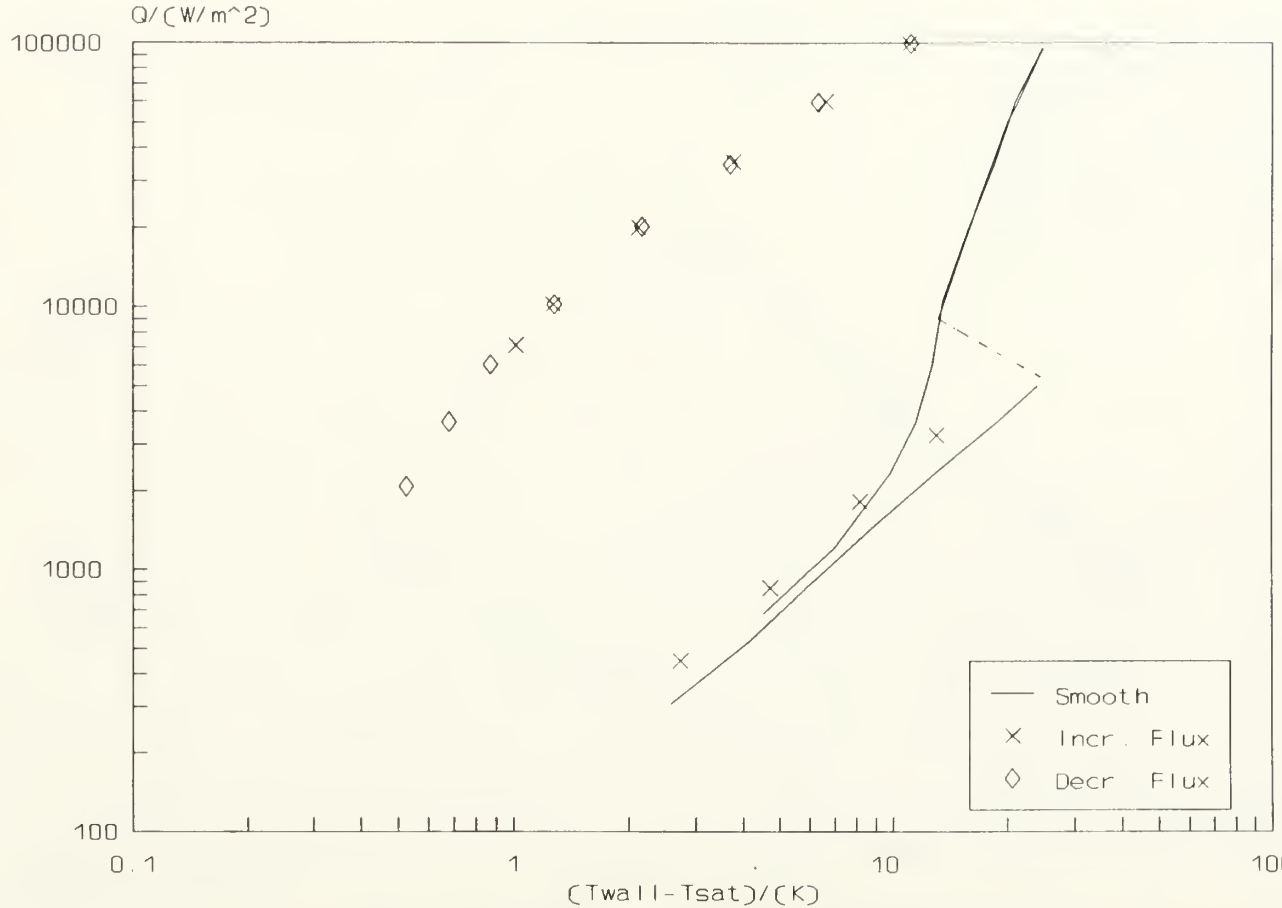


Figure 6.58 Performance Comparison For Boiling R-114/3% Oil Mixture From Thermoexcel-E Tube

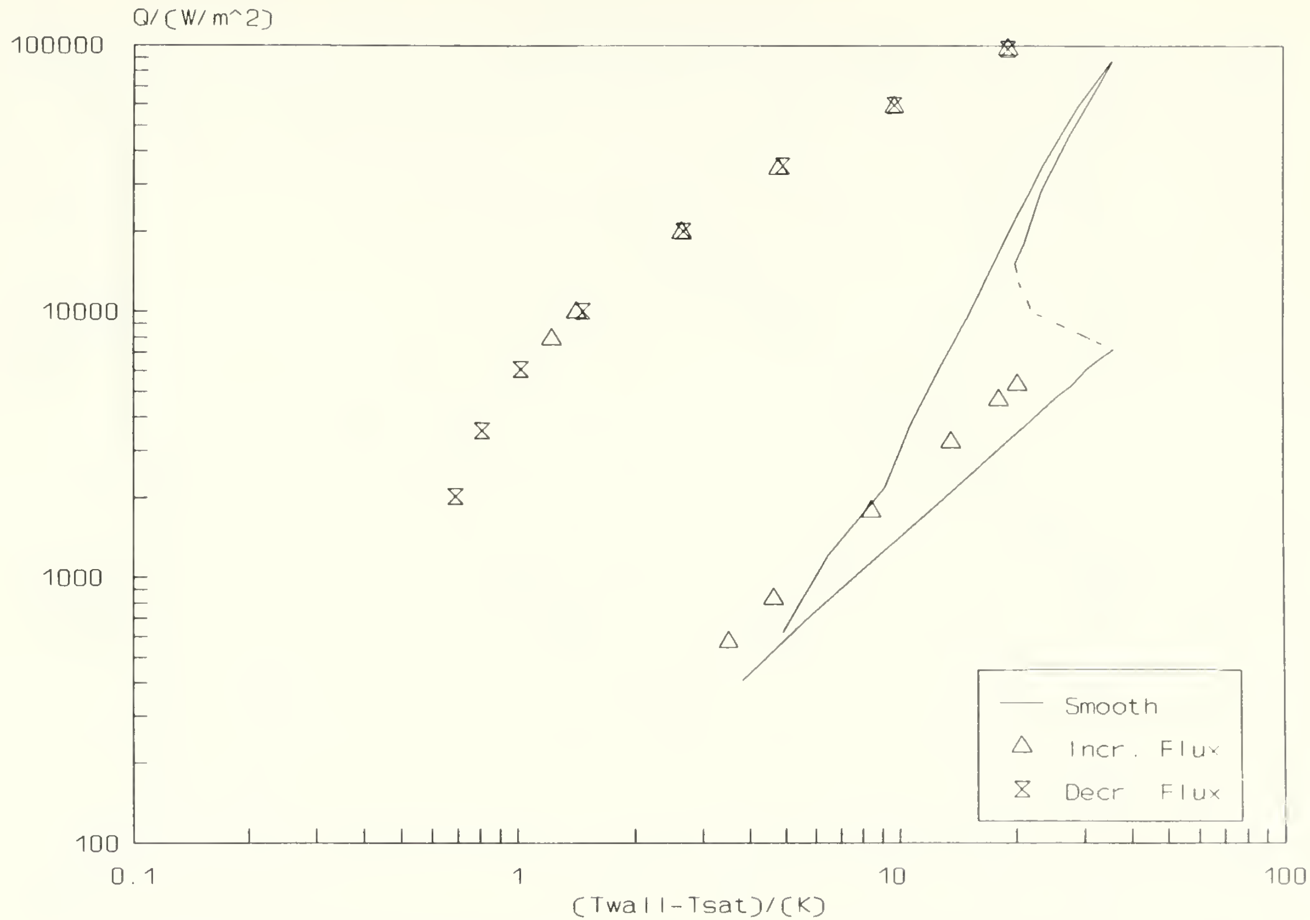


Figure 6.59 Performance Comparison For Boiling R-114/10% Oil Mixture From Thermoexcel-E Tube

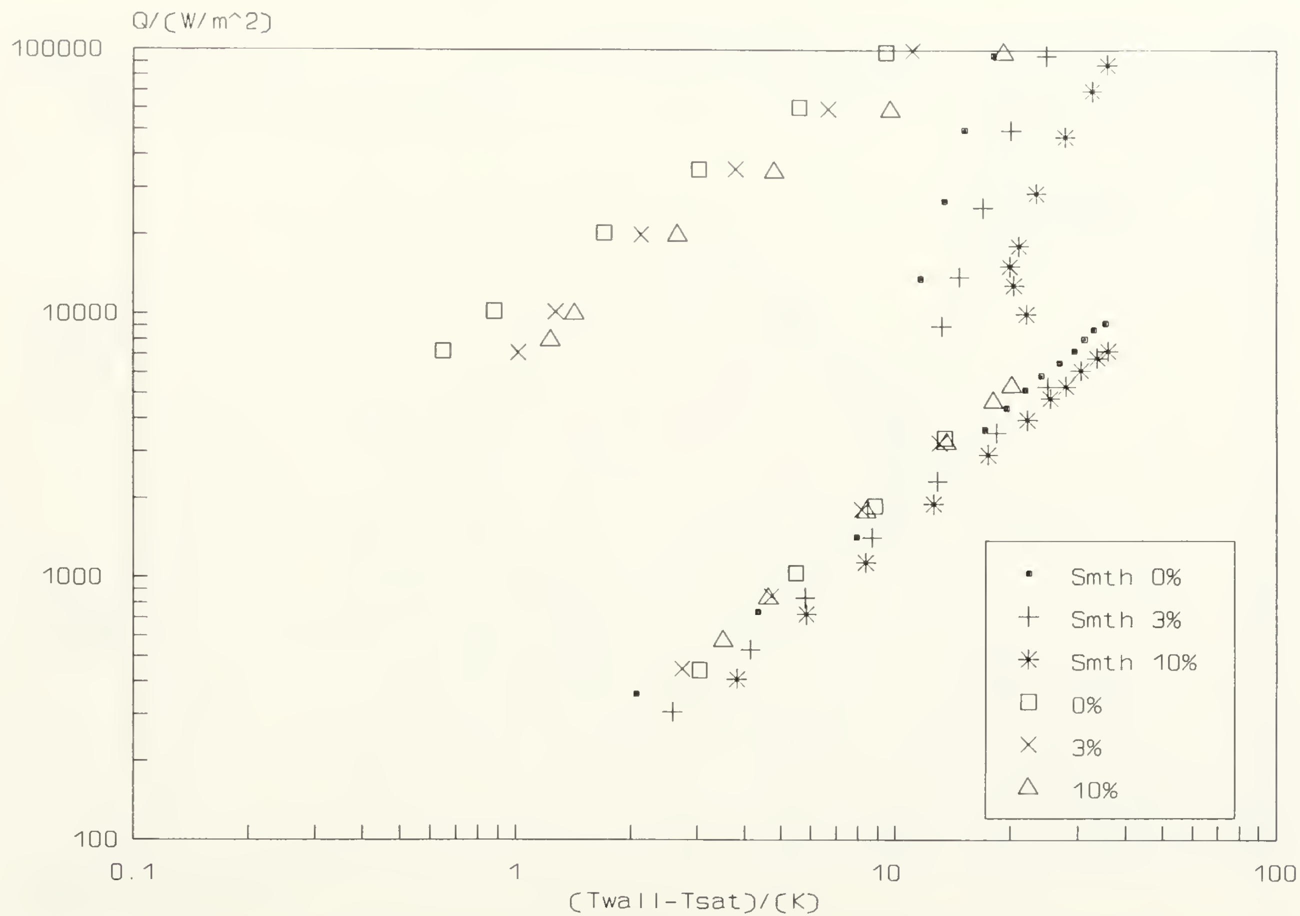


Figure 6.60 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures Increasing Flux From Thermoexcel-E Tube

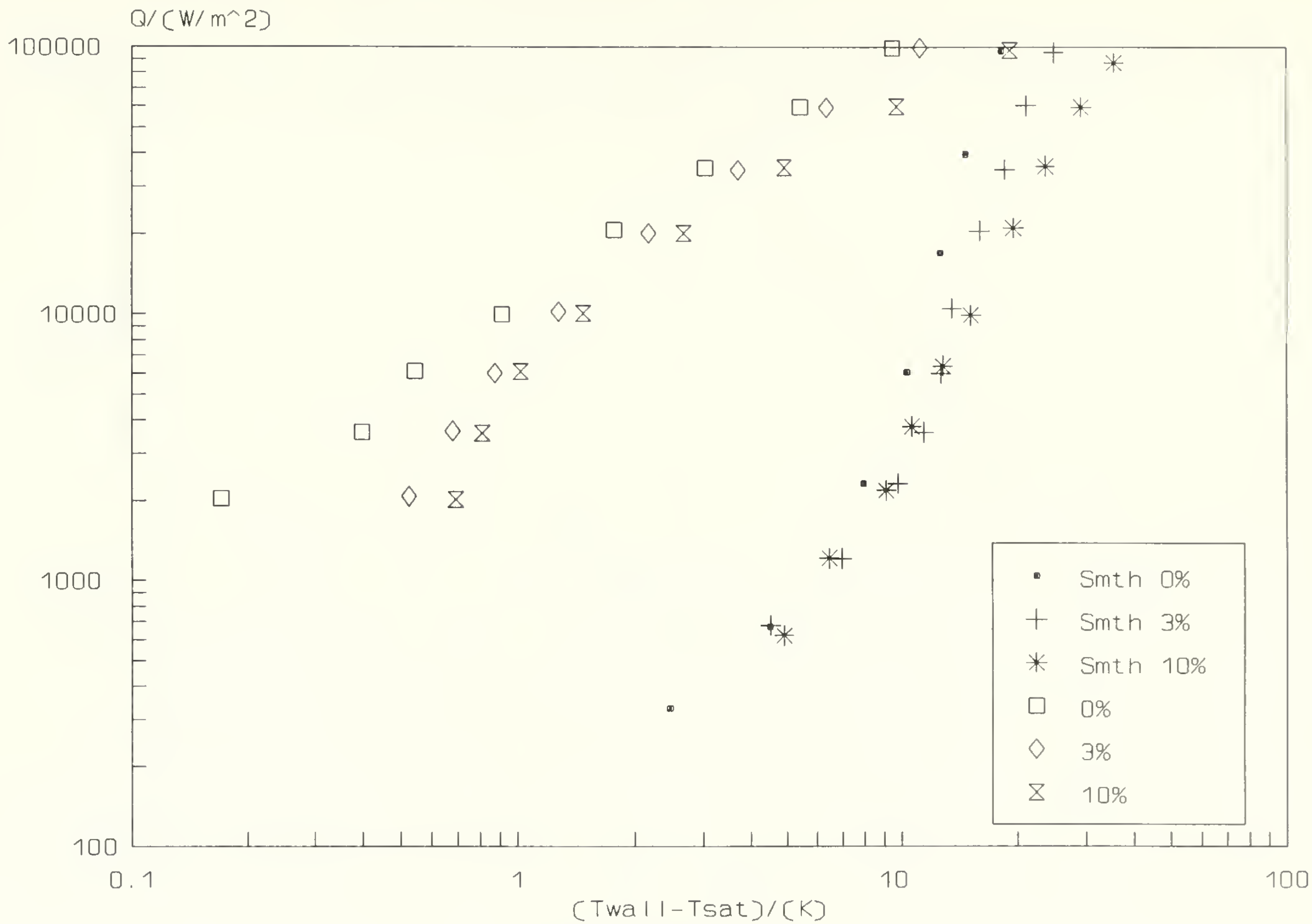


Figure 6.61 Performance Comparison For Boiling R-114/ 0%, 3% & 10% Oil Mixtures Decreasing Flux From Thermoexcel-E Tube

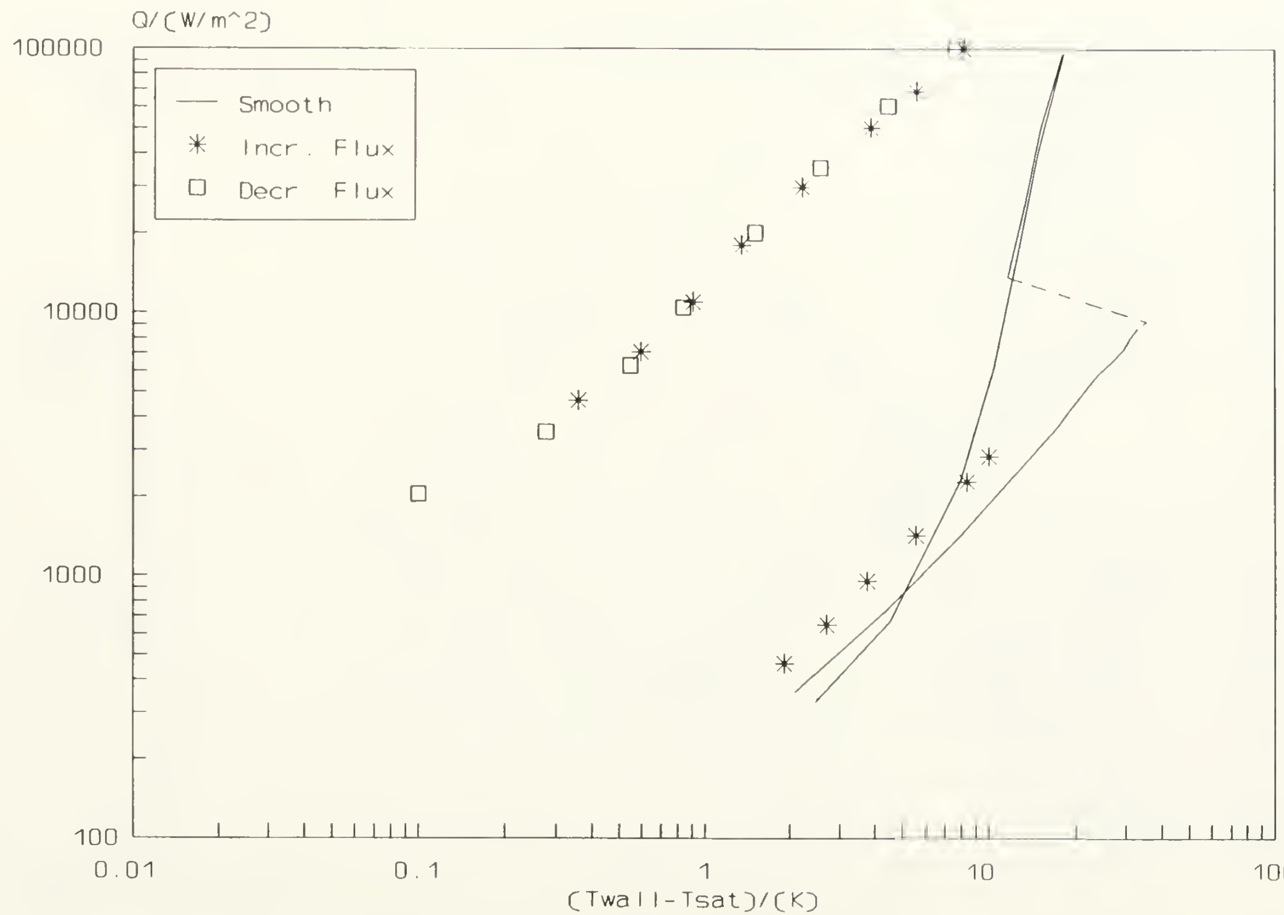


Figure 6.62 Performance Comparison For
Pure R-114 Boiling From
Thermoexcel-HE Tube

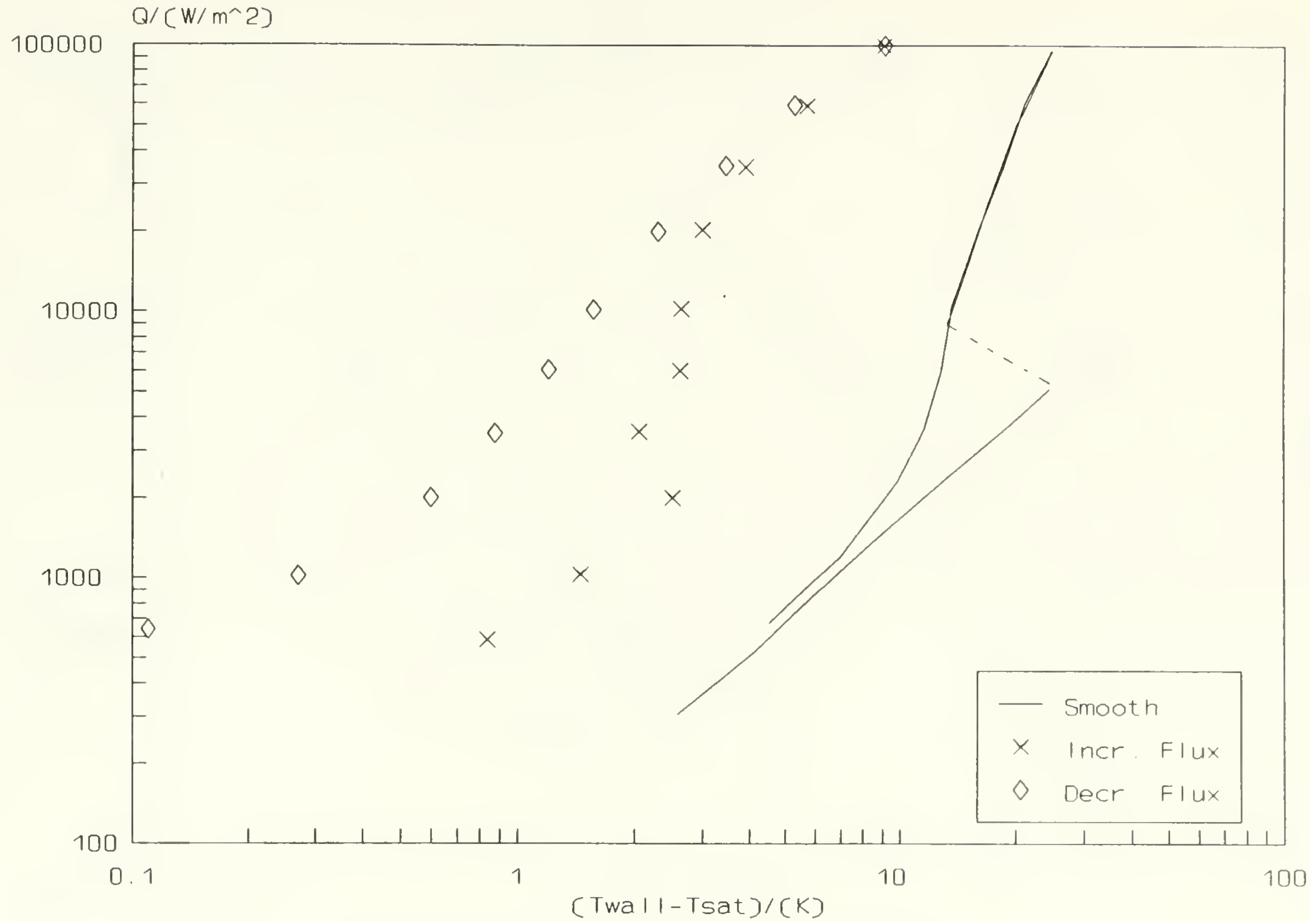


Figure 6.63 Performance Comparison For Boiling R-114/3% Oil Mixture From Thermoexcel-HE Tube

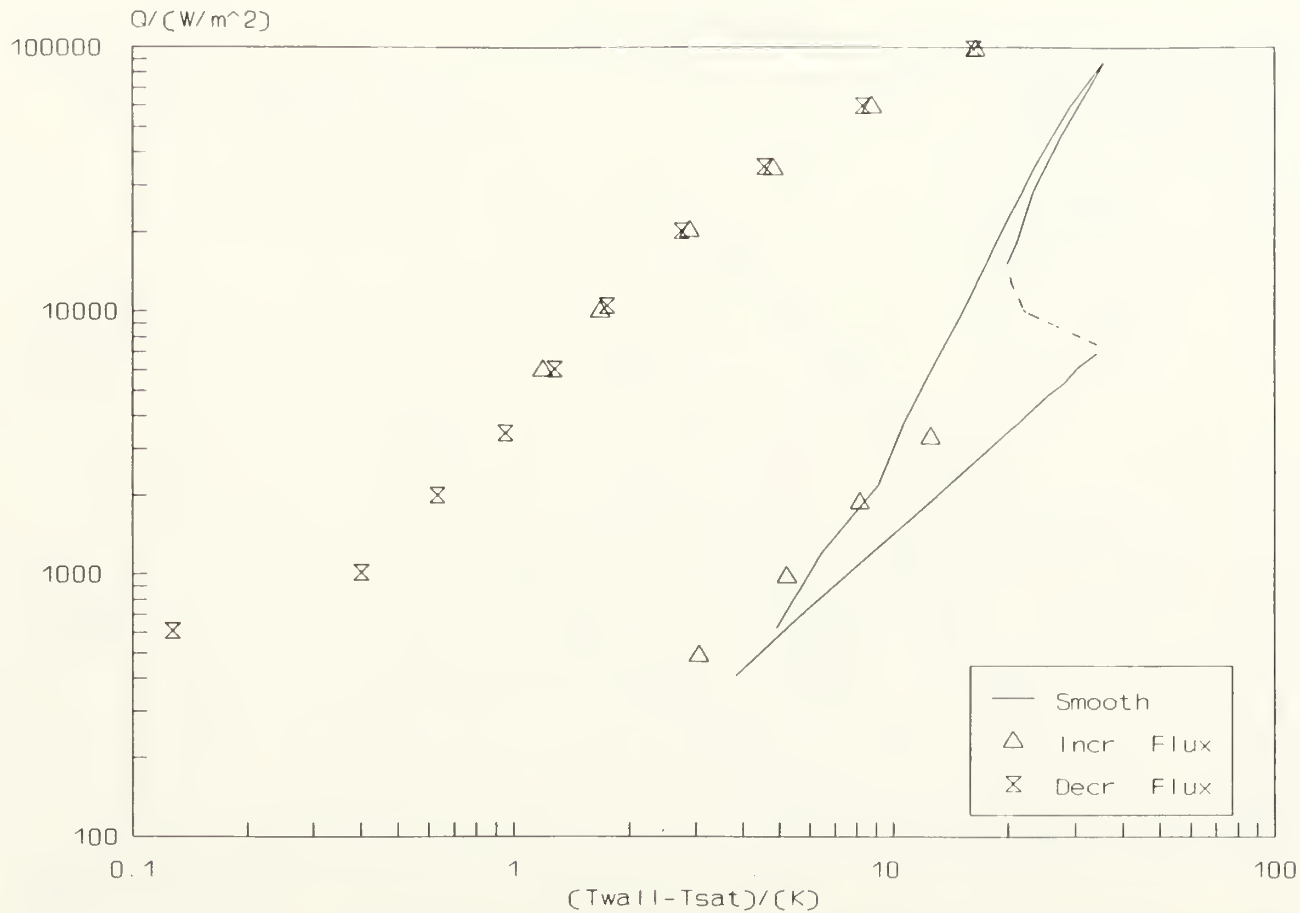


Figure 6.64 Performance Comparison For Boiling R-114/10% Oil Mixture From Thermoexcel-HE Tube

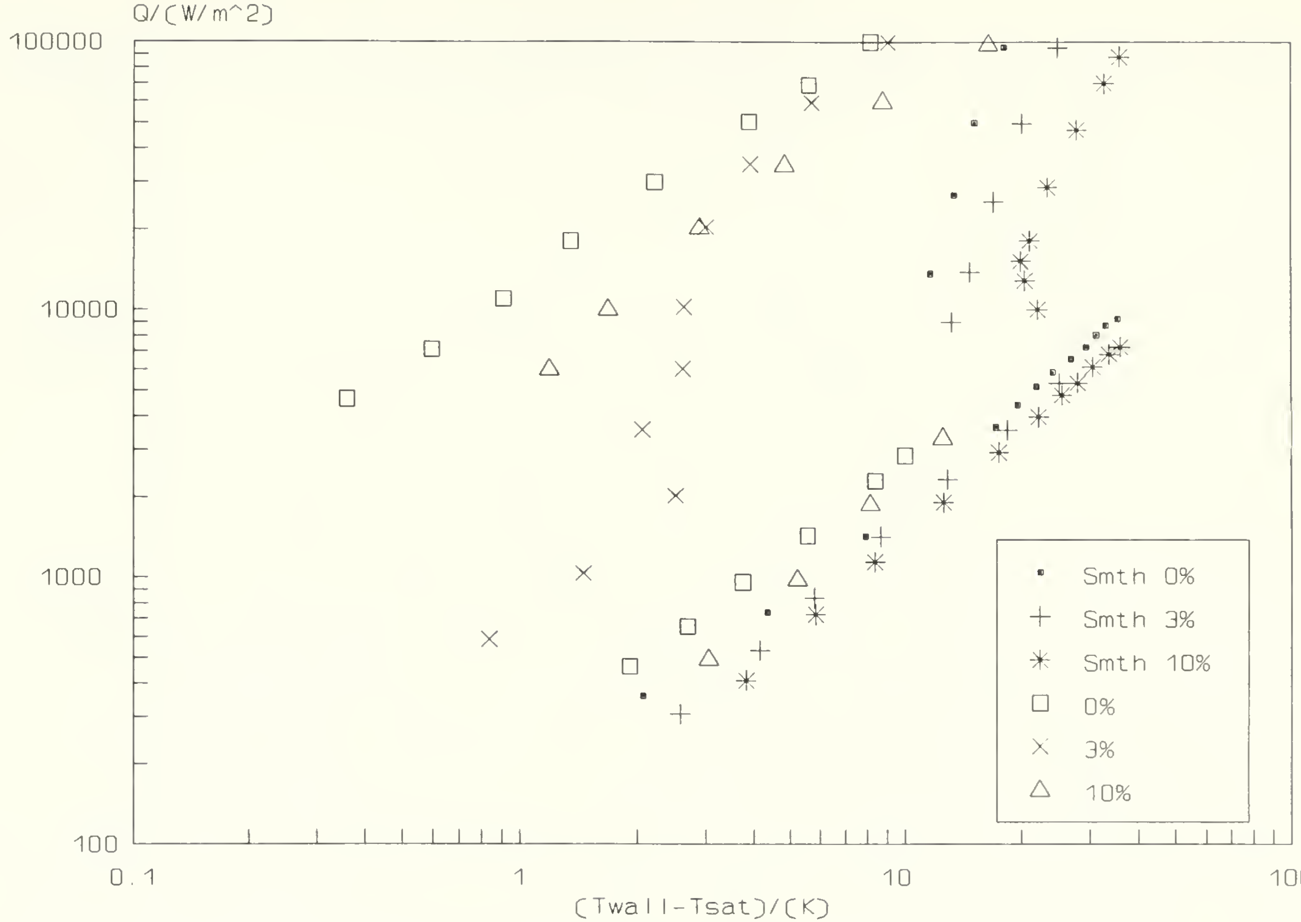


Figure 6.65 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Increasing Flux From Thermoexcel-HE Tube

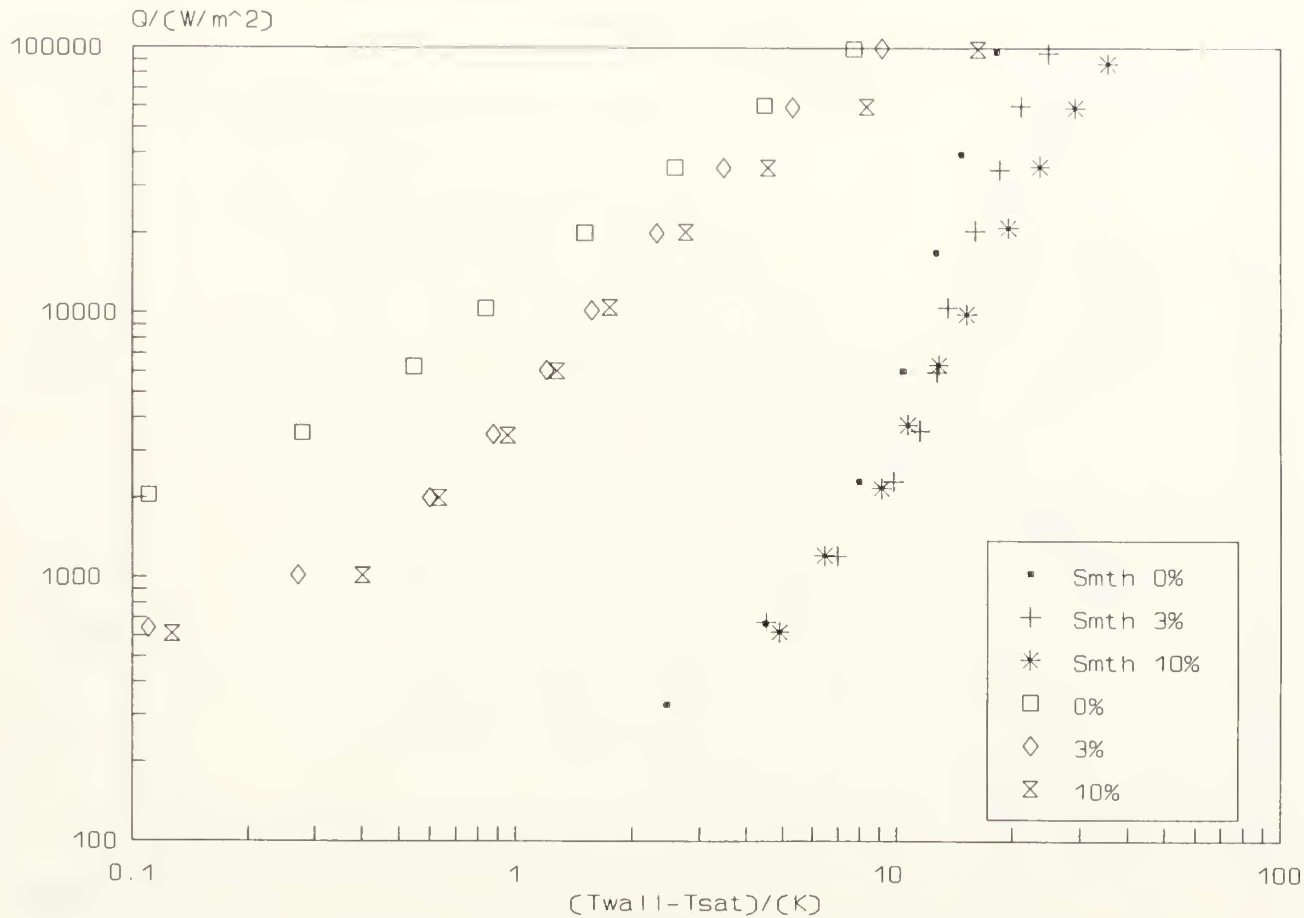


Figure 6.66 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Decreasing Flux From Thermoexcel-HE Tube

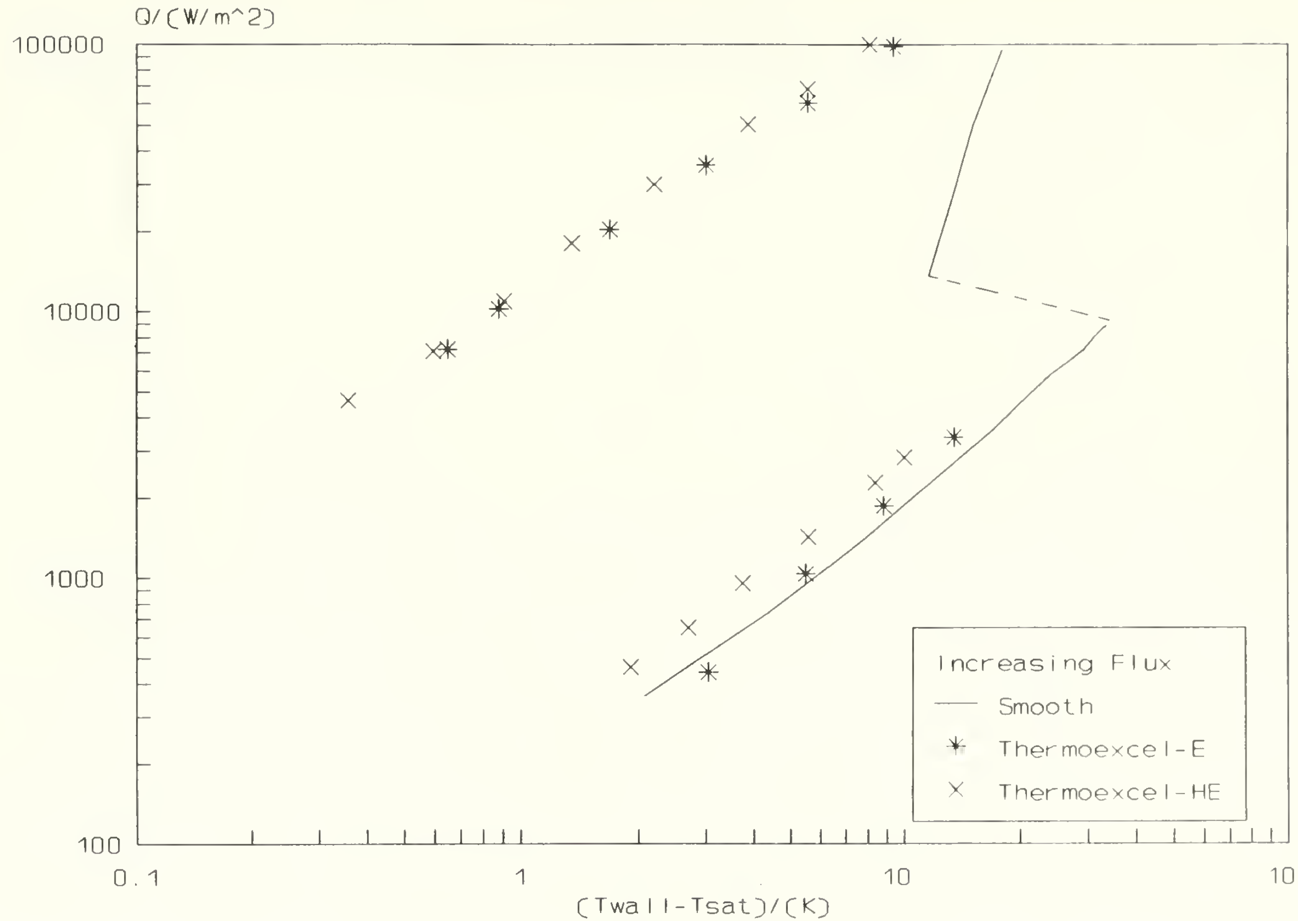


Figure 6.67 Performance Comparison For Boiling Pure R-114 From Thermoexcel-E/HE Tubes

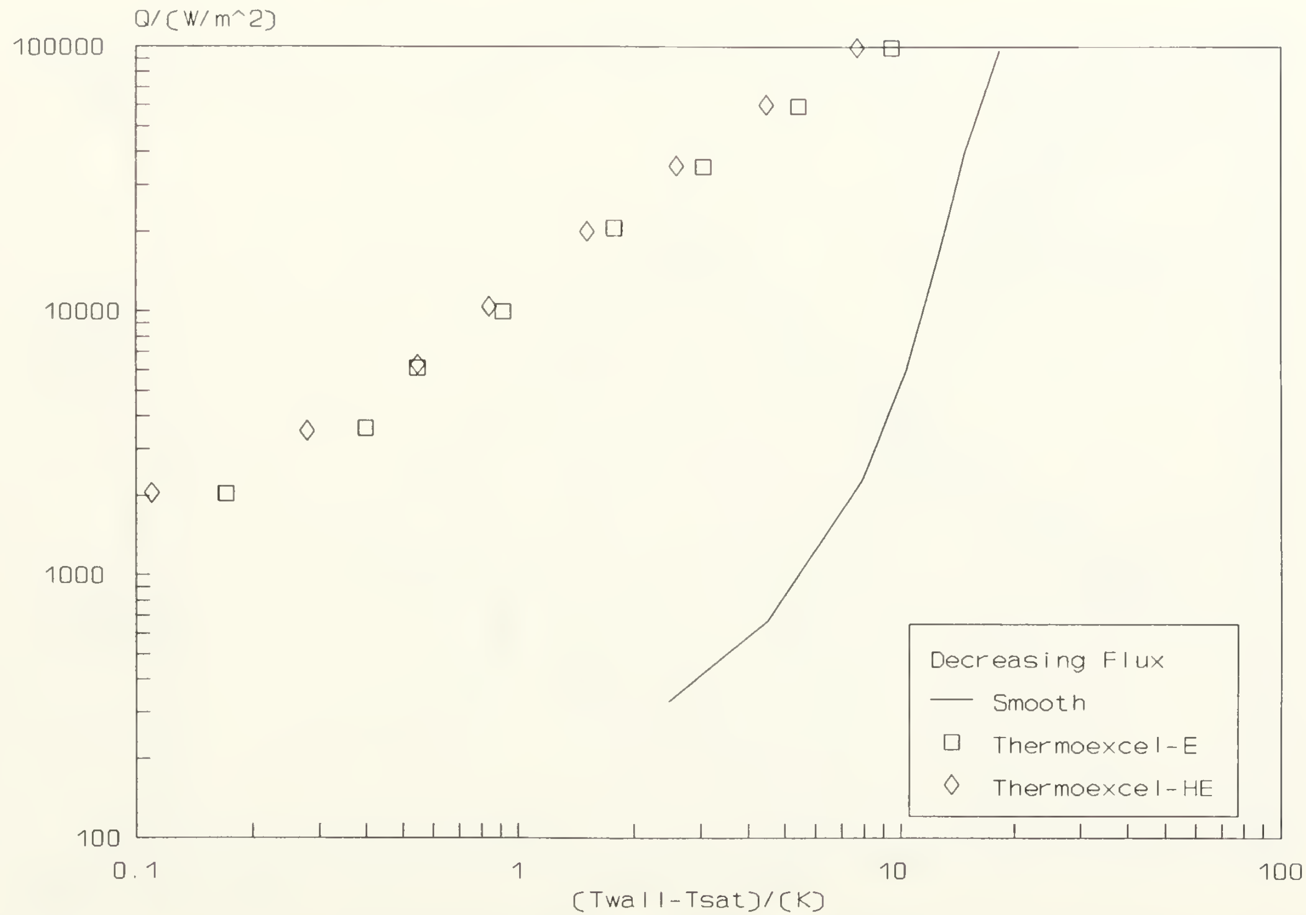


Figure 6.68 Performance Comparison For
Boiling Pure R-114 From
Thermoexcel-E/HE Tubes

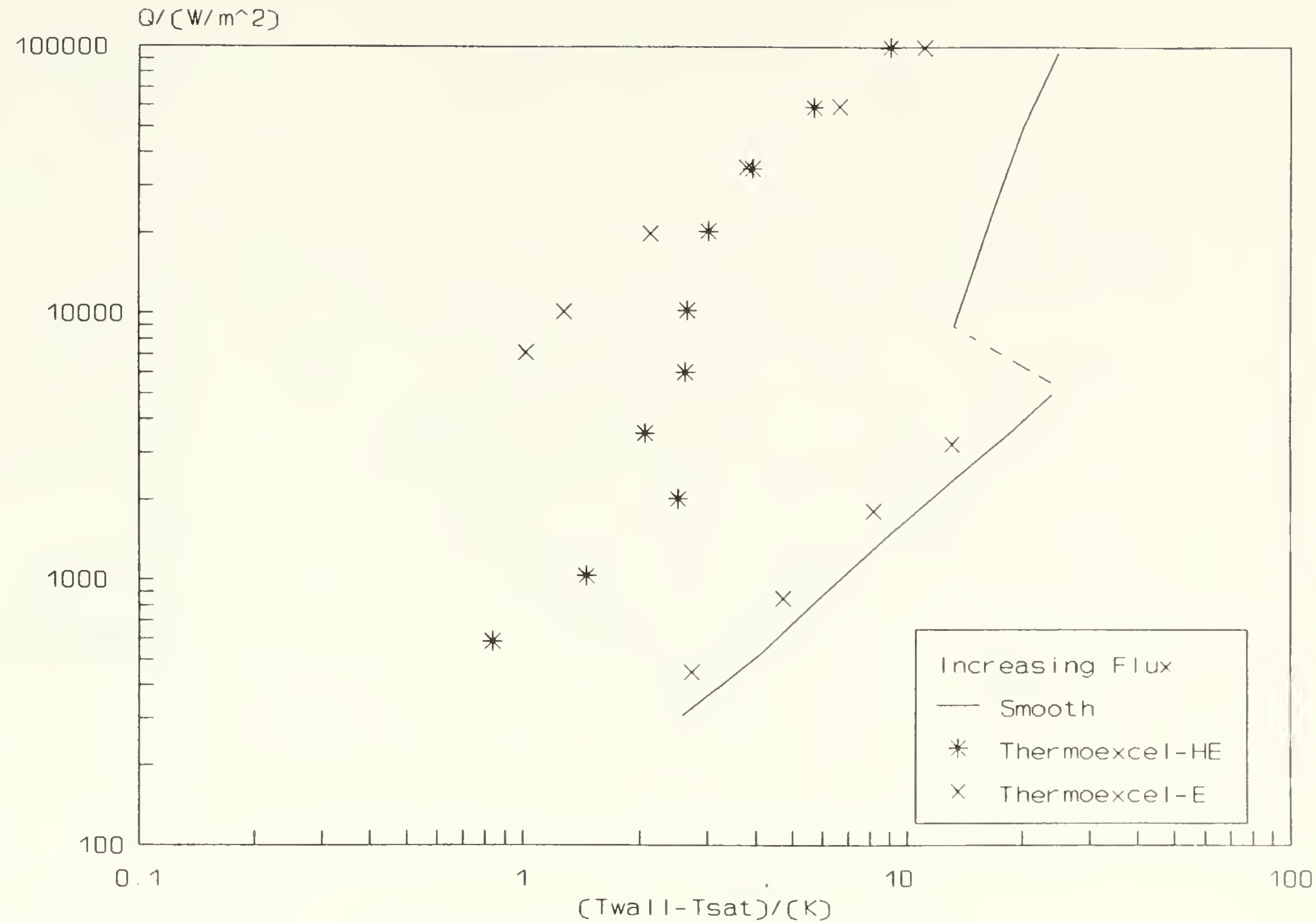


Figure 6.69 Performance Comparison For Boiling R-114/3% Oil Mixture From Thermoexcel-E/HE Tubes

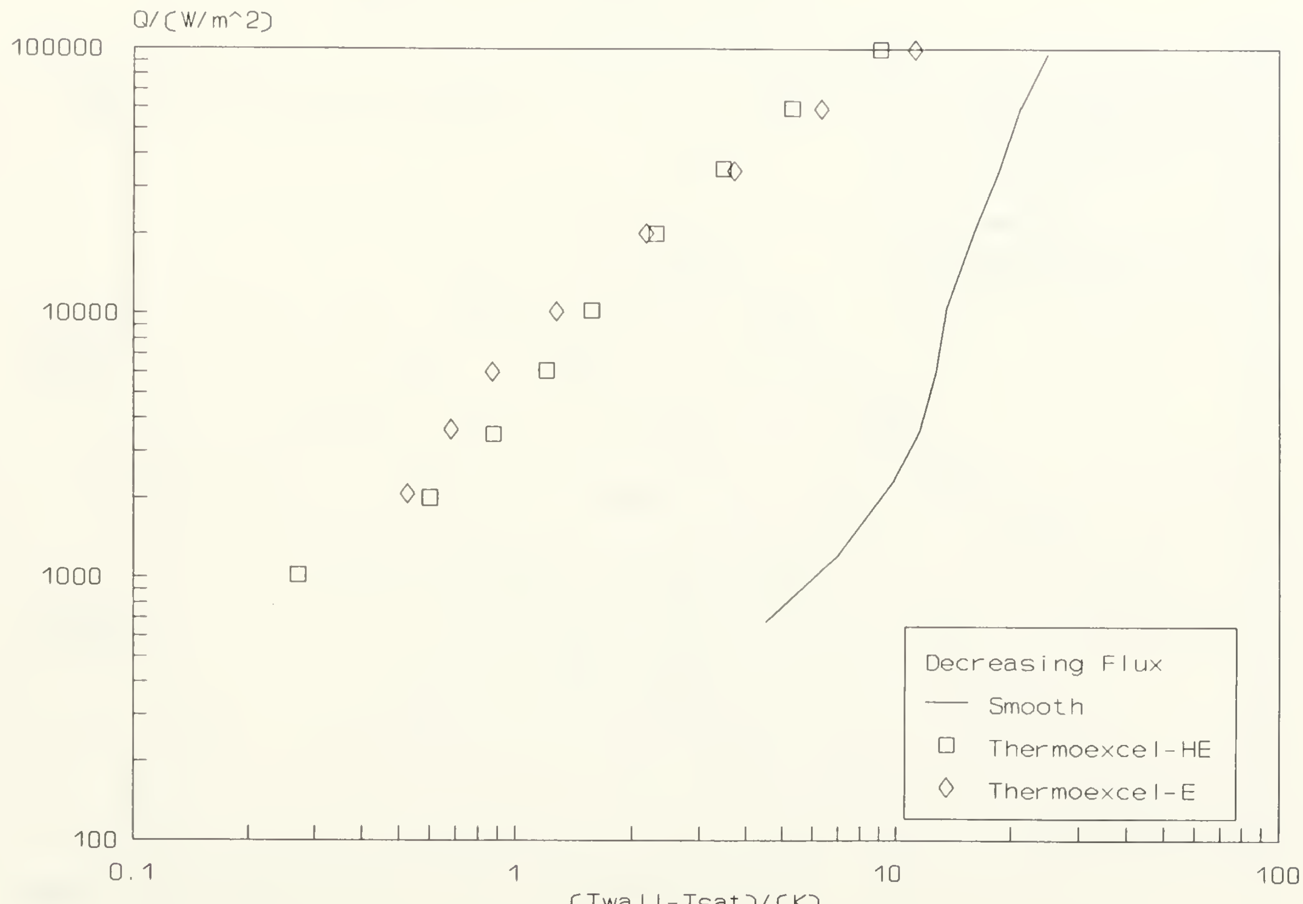


Figure 6.70 Performance Comparison For Boiling R-114/3% Oil Mixture From Thermoexcel-E/HE Tubes

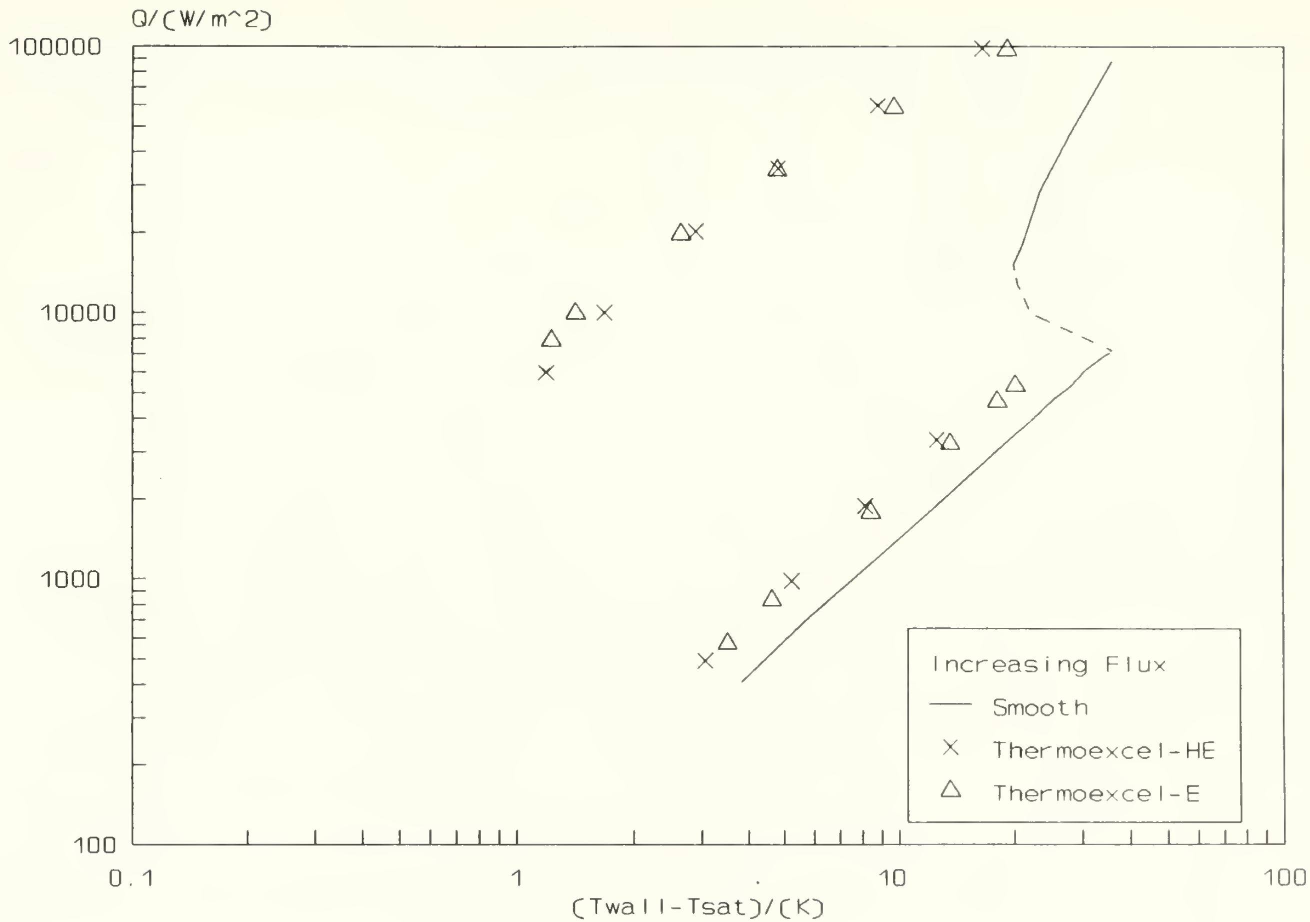


Figure 6.71 Performance Comparison For Boiling R-114/10% Oil Mixture From Thermoexcel-E/HE Tubes

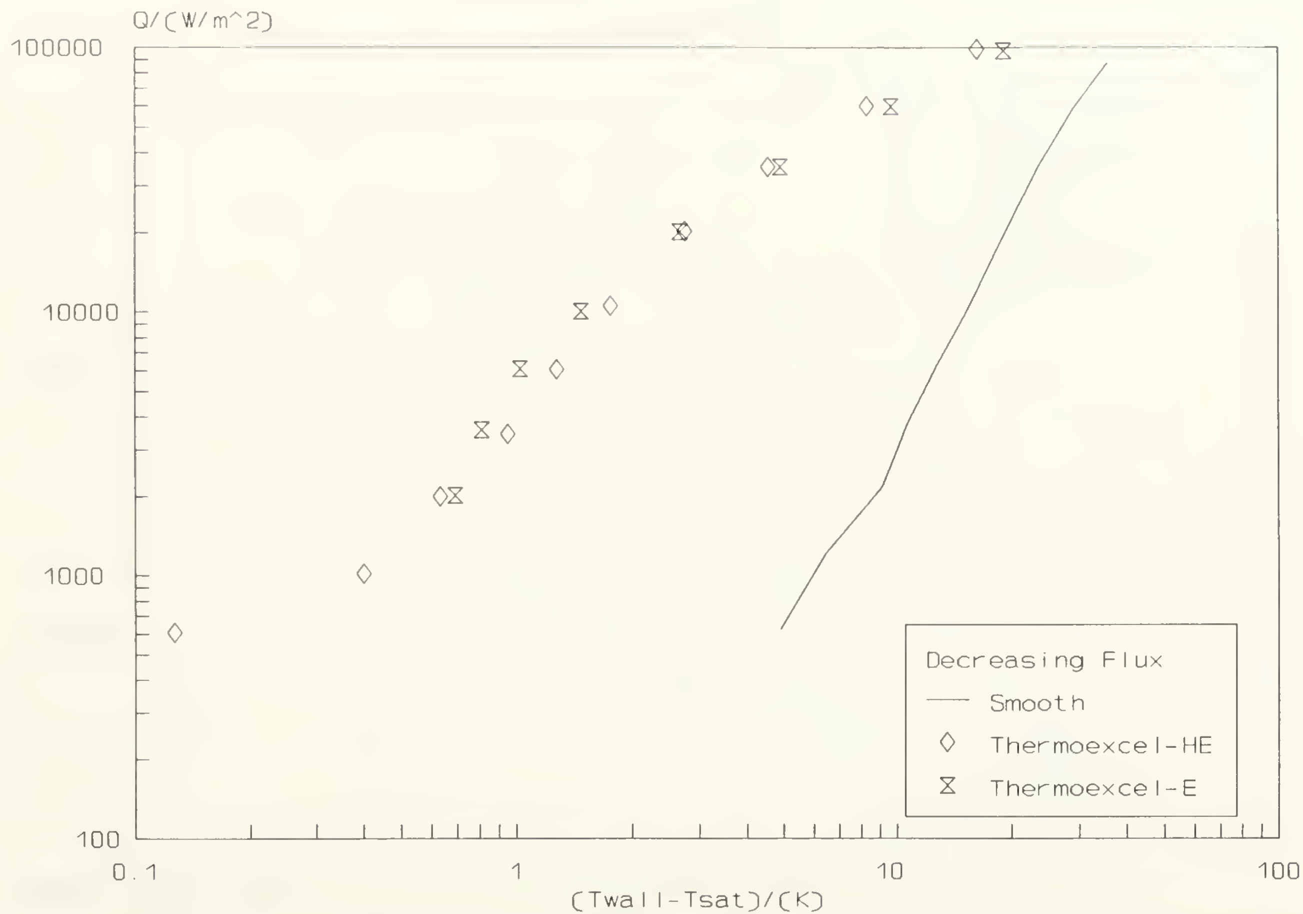


Figure 6.72 Performance Comparison For Boiling R-114/10% Oil Mixture From Thermoexcel-E/HE Tubes

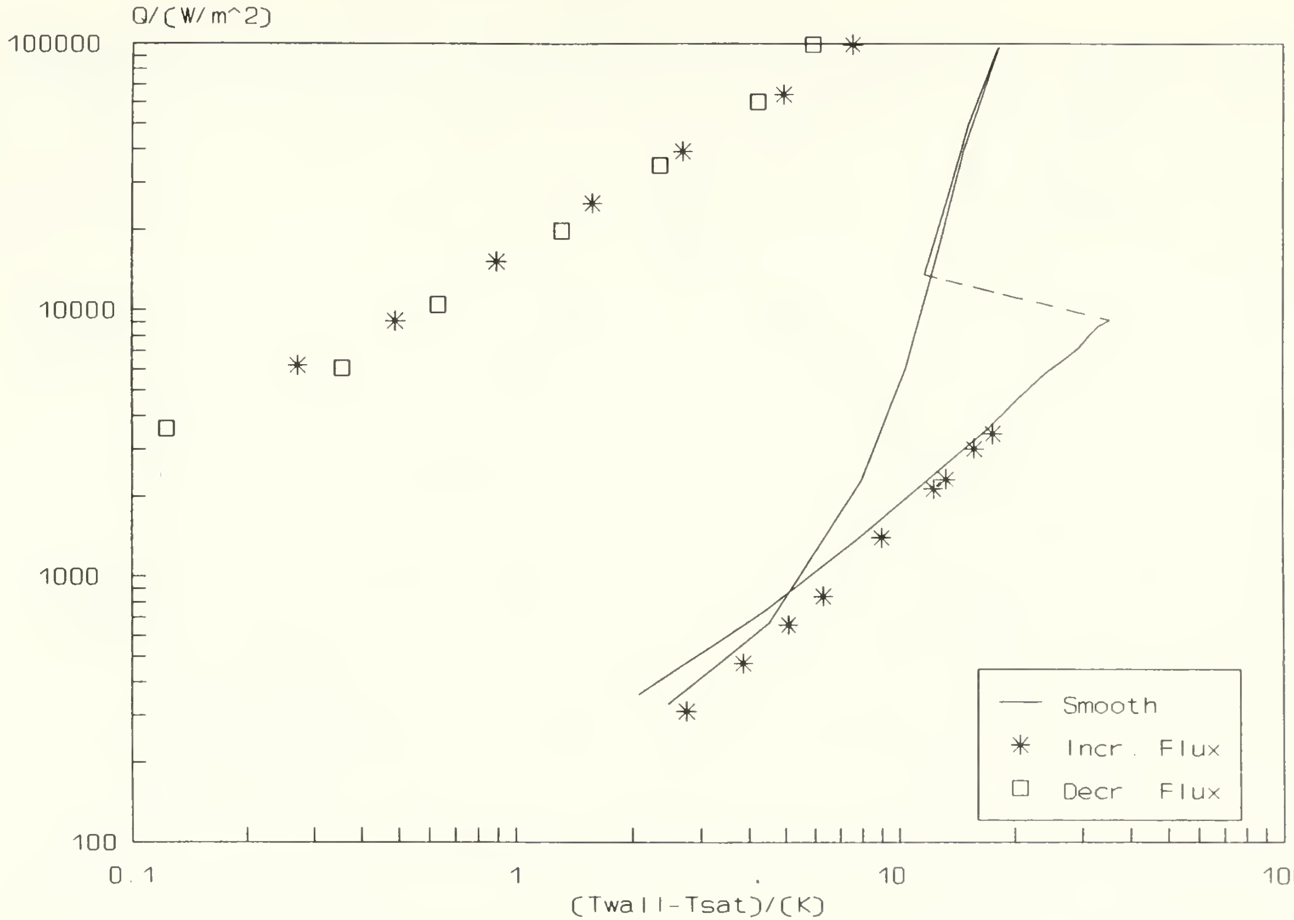


Figure 6.73 Performance Comparison For
Pure R-114 Boiling From
Turbo-B Tube

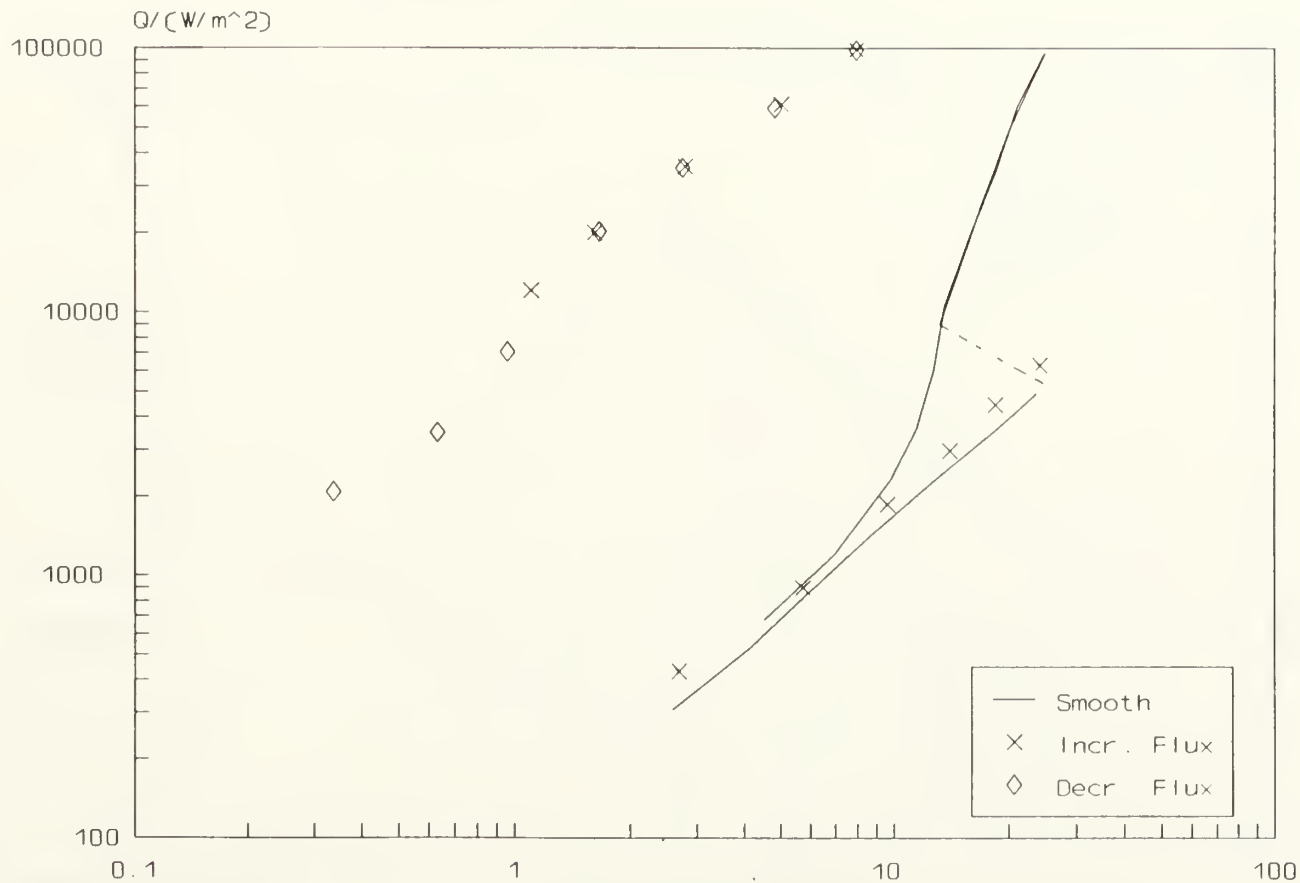


Figure 6.74 Performance Comparison For Boiling R-114/3% Oil Mixture From Turbo-B Tube

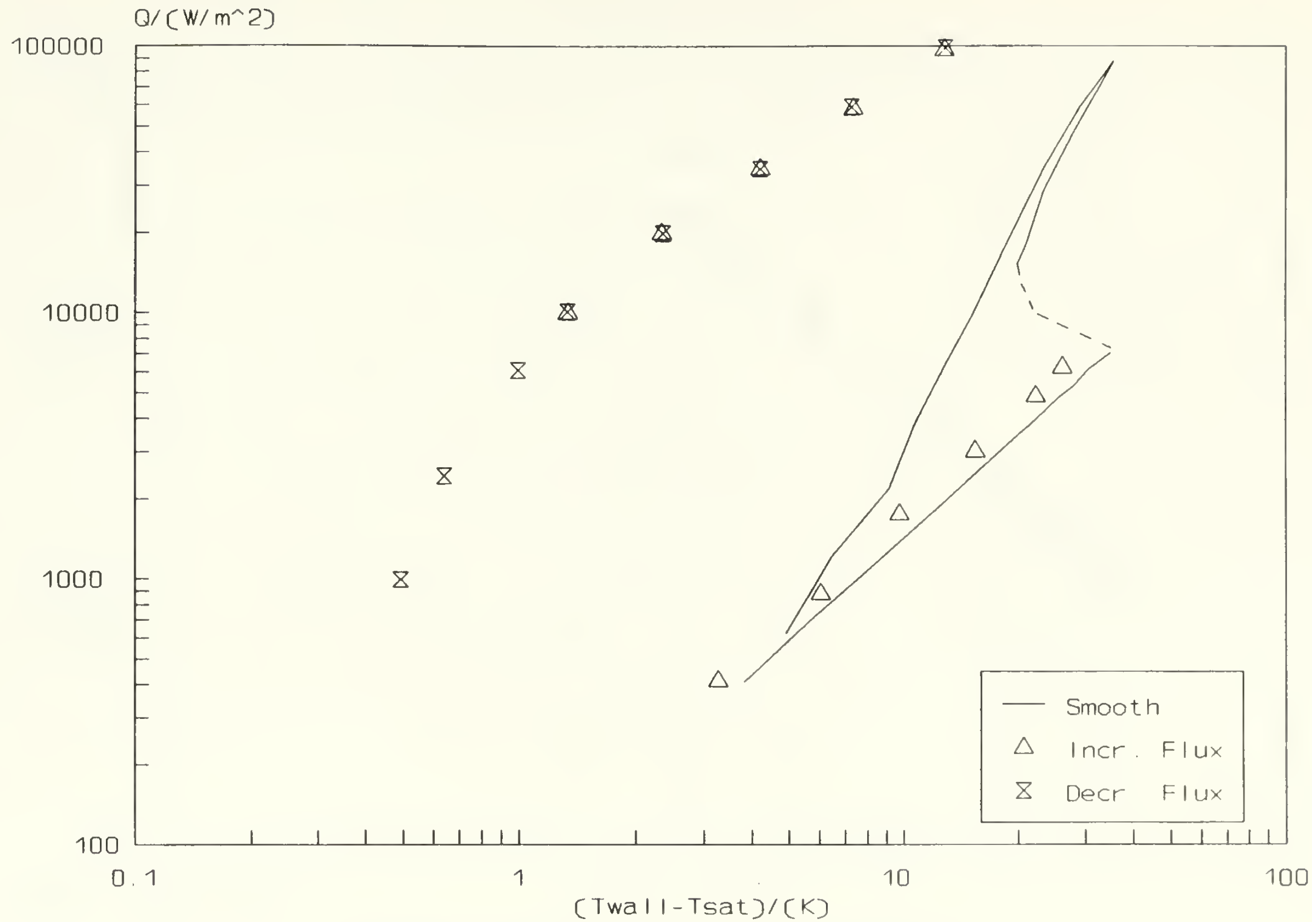


Figure 6.75 Performance Comparison For Boiling R-114/10% Oil Mixture From Turbo-B Surface

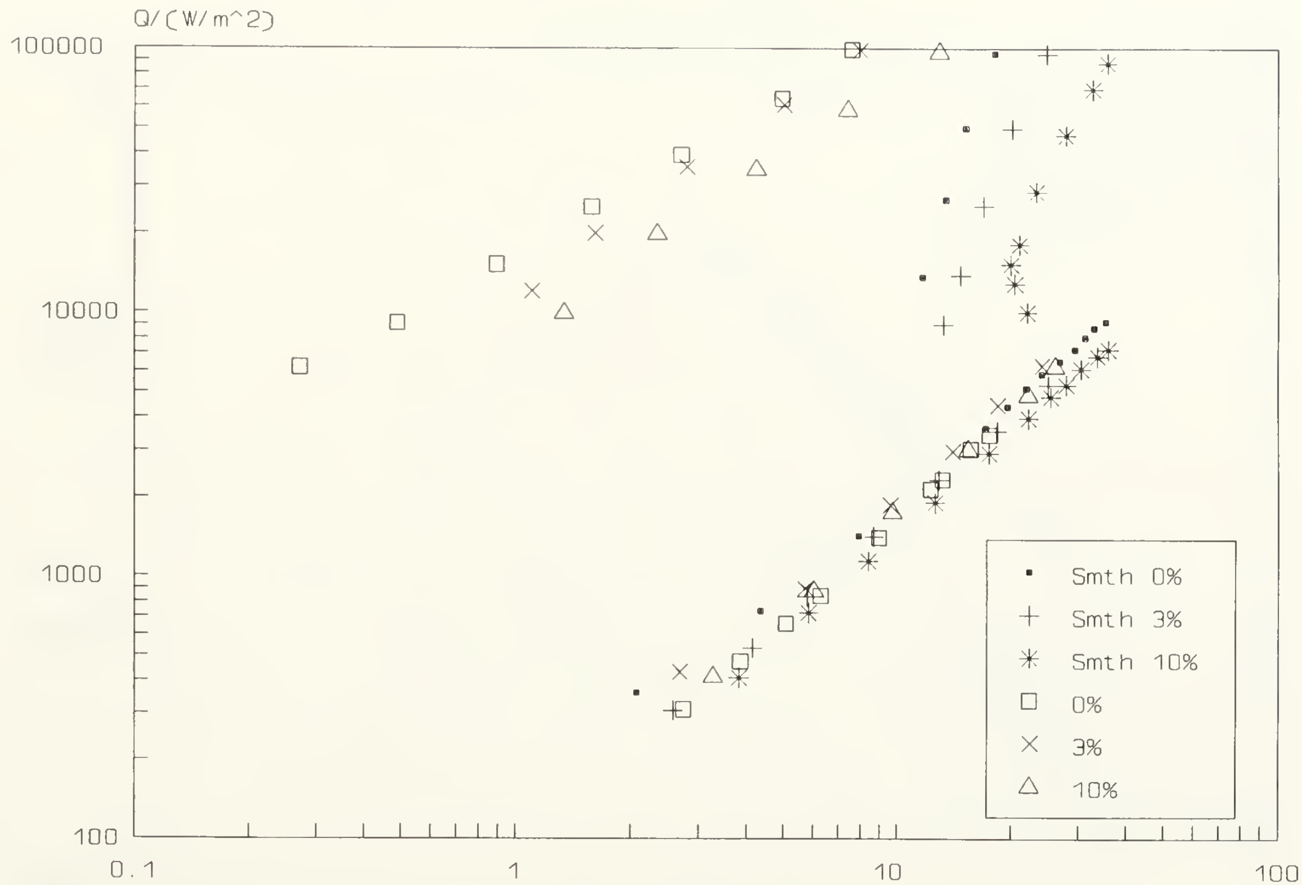


Figure 6.76 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Increasing Flux From Turbo-B Tube

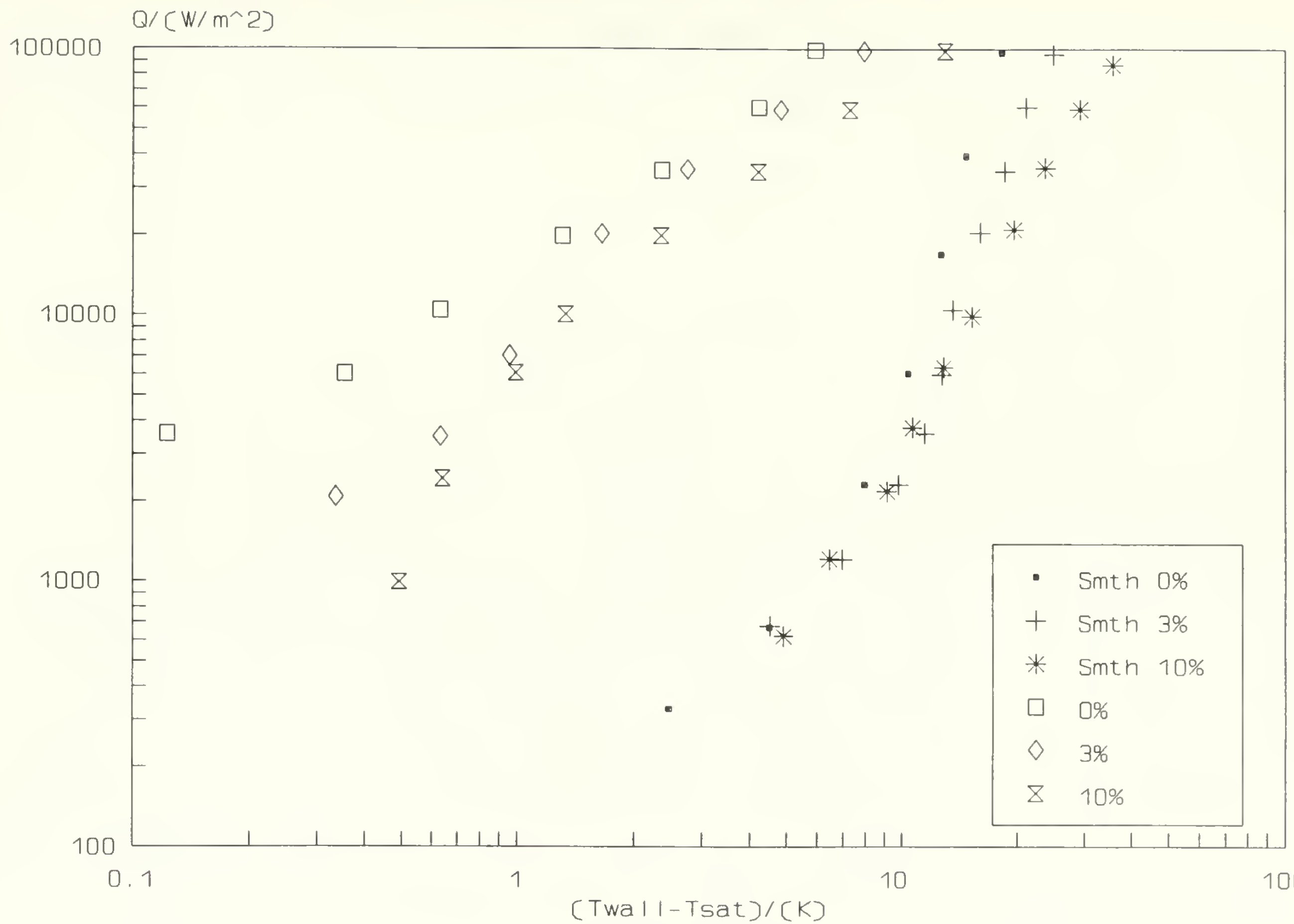


Figure 6.77 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Decreasing Flux From Turbo-B Tube

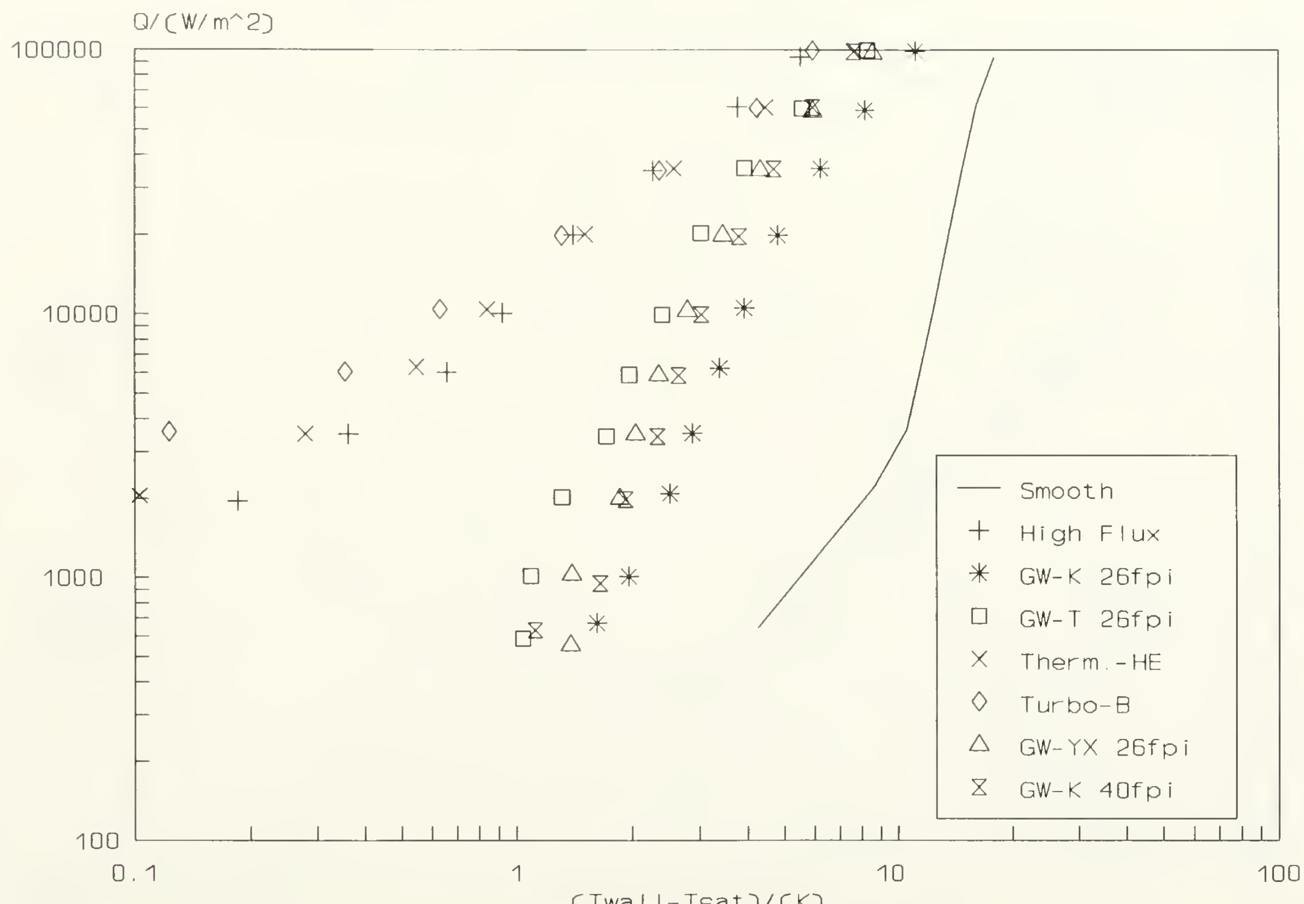


Figure 6.78 Performance Comparison For Boiling Pure R-114 Boiling From Smooth and Enhanced Tubes

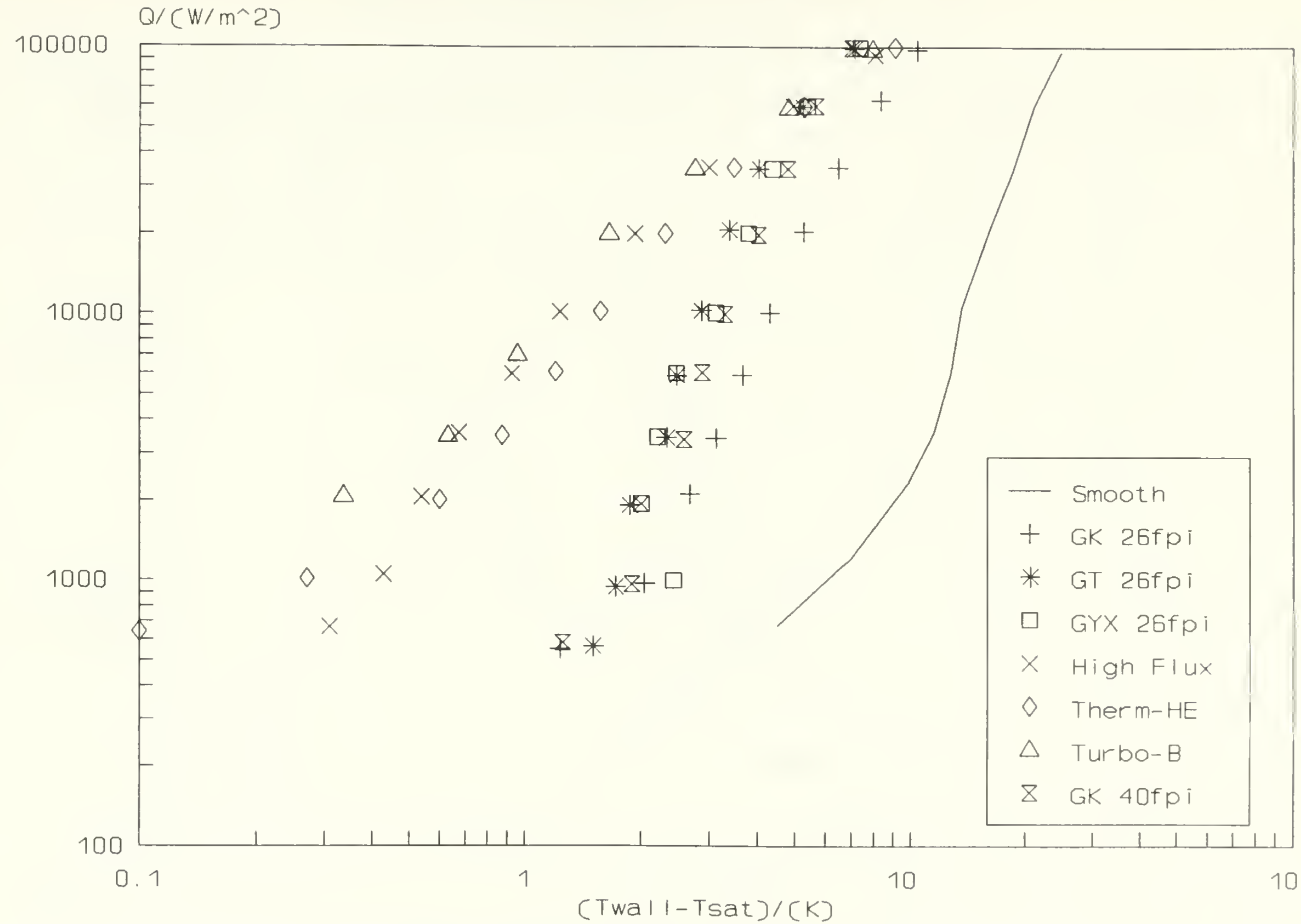


Figure 6.79 Performance Comparison For Boiling R-114/3% Oil Mixture From Smooth and Enhanced Tubes

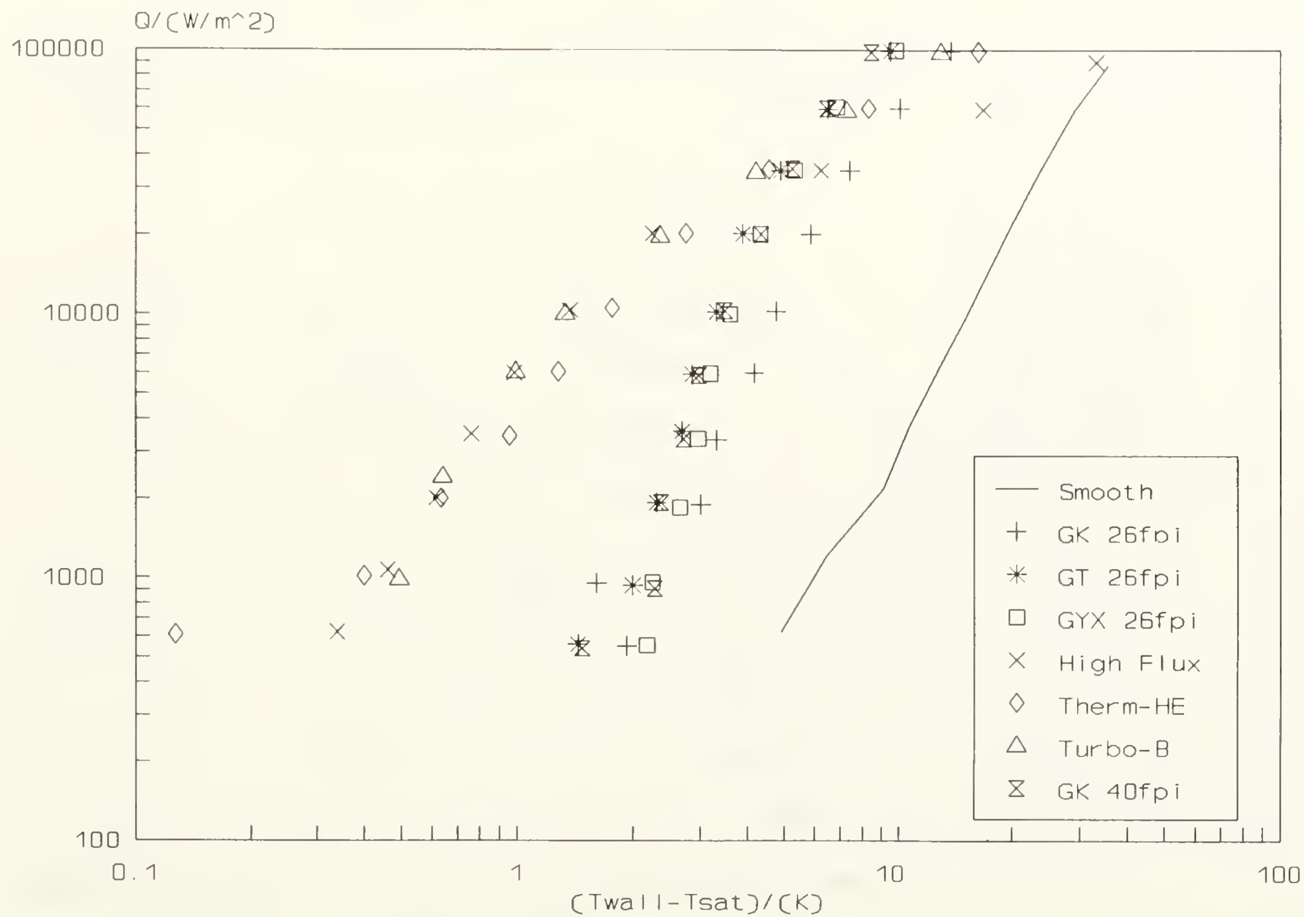


Figure 6.80 Performance Comparison For Boiling R-114/10% Oil Mixture From Smooth and Enhanced Tubes

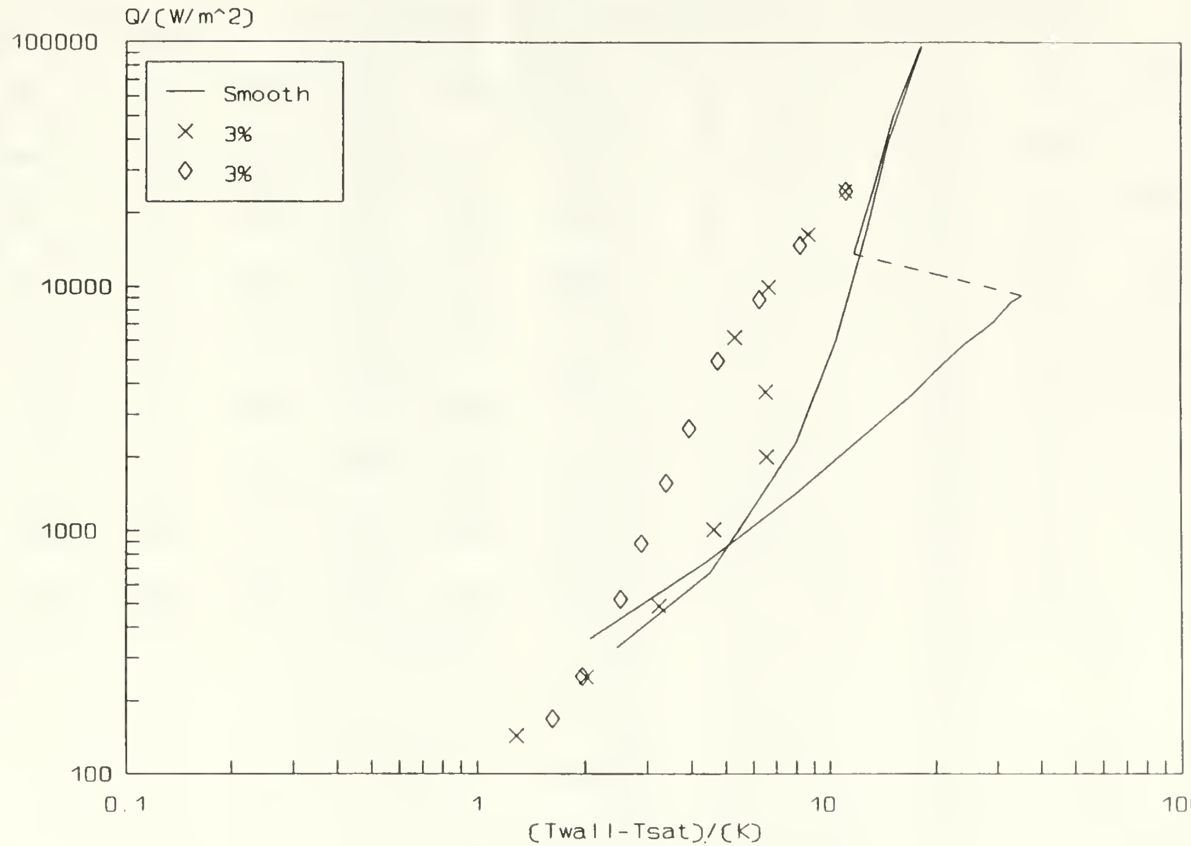


Figure 6.81 Performance Comparison For Pure R-114 Boiling From GEWA-K 26 fpi Using Actual Wetted Surface Area

Heat Flux /(kW/m^2)	3.5			10			35			100		
Oil Conc. /(%)	0	3	10	0	3	10	0	3	10	0	3	10
Tube Type												
Smooth	1	1	1	1	1	1	1	1	1	1	1	1
GK-26fpi	3.6	3.8	3.2	3.1	3.1	3.3	2.4	2.9	3.2	1.6	2.4	2.6
GK-40fpi	4.6	4.4	4	4.1	4.1	4.4	3.1	3.9	4.6	2.4	3.6	4.2
GT-19fpi	6.6	6.1	5.3	5.4	5.4	5.7	3.1	4.3	5.2	1.8	3	3.5
GT-26fpi	6.2	5	3.9	5.2	4.7	4.6	3.7	4.6	4.8	2.2	3.5	3.7
GX-26fpi	5.3	5.2	3.5	4.4	4.4	4.3	3.4	4.3	4.4	2.1	3.4	3.6
High Flux	30.9	17.2	13.6	13.5	11.3	10.9	6.4	6.2	3.8	3.3	3.1	1.1
T-HE	26.3	17.4	12.8	13.6	10.5	10.2	4.8	5.1	4.8	1.9	2.2	1.9
T-E	38.9	13.1	10.9	14.6	8.5	8.5	5.7	5.3	5.2	2.6	2.7	2.2
Turbo-B	105	18	14.2	19.4	12.1	11.8	6.2	6.7	5.6	3.1	3.1	2.7

GK = GEWA-K GT = GEWA-T GX = GEWA-YX T-HE = Thermoexcel-HE T-E = Thermoexcel-E

TABLE III. HEAT TRANSFER COEFFICIENT ENHANCEMENT RATIOS FOR SMOOTH VERSUS ENHANCED SURFACES

VII. CONCLUSIONS

1. Accurate and repeatable boiling heat-transfer data using R-114 and R-114/oil mixtures was obtained on ten enhanced tube surfaces.

2. Three distinct groups of boiling tubes can be identified by structure and boiling performance: smooth, finned and reentrant cavity.

3. Significant increase in performance was observed for reentrant cavity surfaces versus either the finned or smooth surfaces within the nucleating regime at all heat fluxes tested.

4. Degradation in boiling performance accompanied increases in oil concentration within the nucleating regime. Most notably, the high flux surface performed comparably to a smooth surface at the highest flux tested.

5. Within the convection regime all tube surfaces tested performed equally well. No significant effect of oil concentration can be observed up to incipient nucleation.

6. Distinct temperature overshoot within the convection regime occurs repeatably in all tube surfaces tested. The reentrant cavity surfaces exhibit the most extreme overshoot versus either the finned or smooth surfaces. Oil concentration has no significant effect.

VIII. RECOMMENDATIONS

1. Due to the way a real flooded evaporator operates, it would be preferable to heat the tube within the single tube apparatus with hot water.

2. As a complement to present single tube and bundle tube studies, the present single tube apparatus should be modified to accommodate two vertically aligned boiling tubes in order to study the effects of multiple tubes and variation of tube pitch to diameter ratios.

3. The physical properties of the R-114/oil mixtures tested should be measured for comparison to the predictions used in the data reduction program and for better understanding of the mechanisms driving the degradation in heat transfer performance.

4. Neutrally buoyant particles should be placed in the pool to facilitate study of the circulation patterns within the flooded evaporator in more detail.

5. A high speed camera should be used to study the nucleation process and circulation patterns in more detail.

APPENDIX A: THERMOPHYSICAL PROPERTIES OF R-114

The following thermophysical properties of saturated R-114 are plotted versus temperature °C:

1.	Liquid Density (kg/m^3)
2.	Liquid Dynamic Viscosity (Pa*s)
3.	Liquid Thermal Conductivity (W/m*K)
4.	Liquid Specific Heat (J/kg*K)
5.	Latent Heat (J/kg)

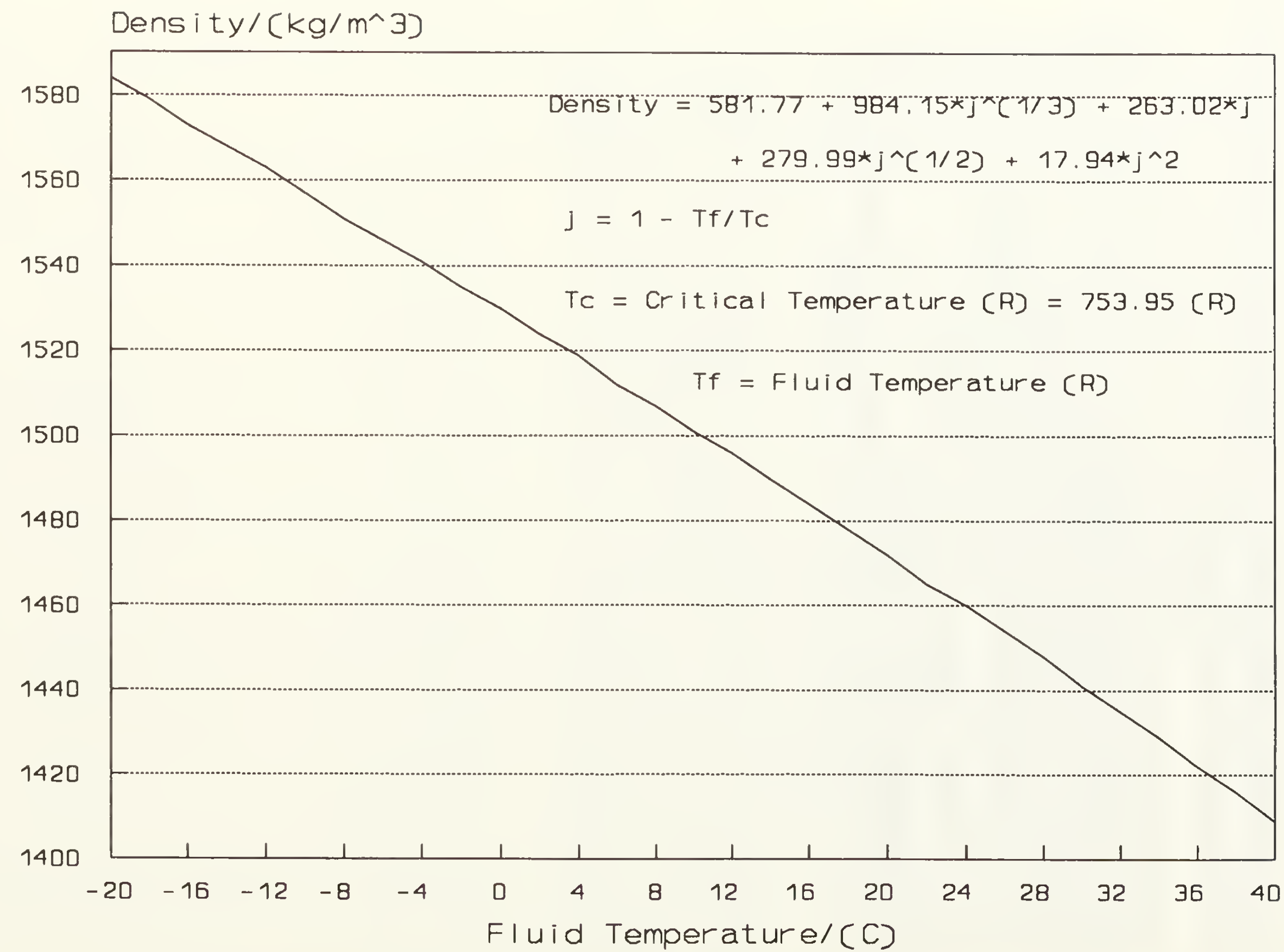


Figure A.1 Density of R-114

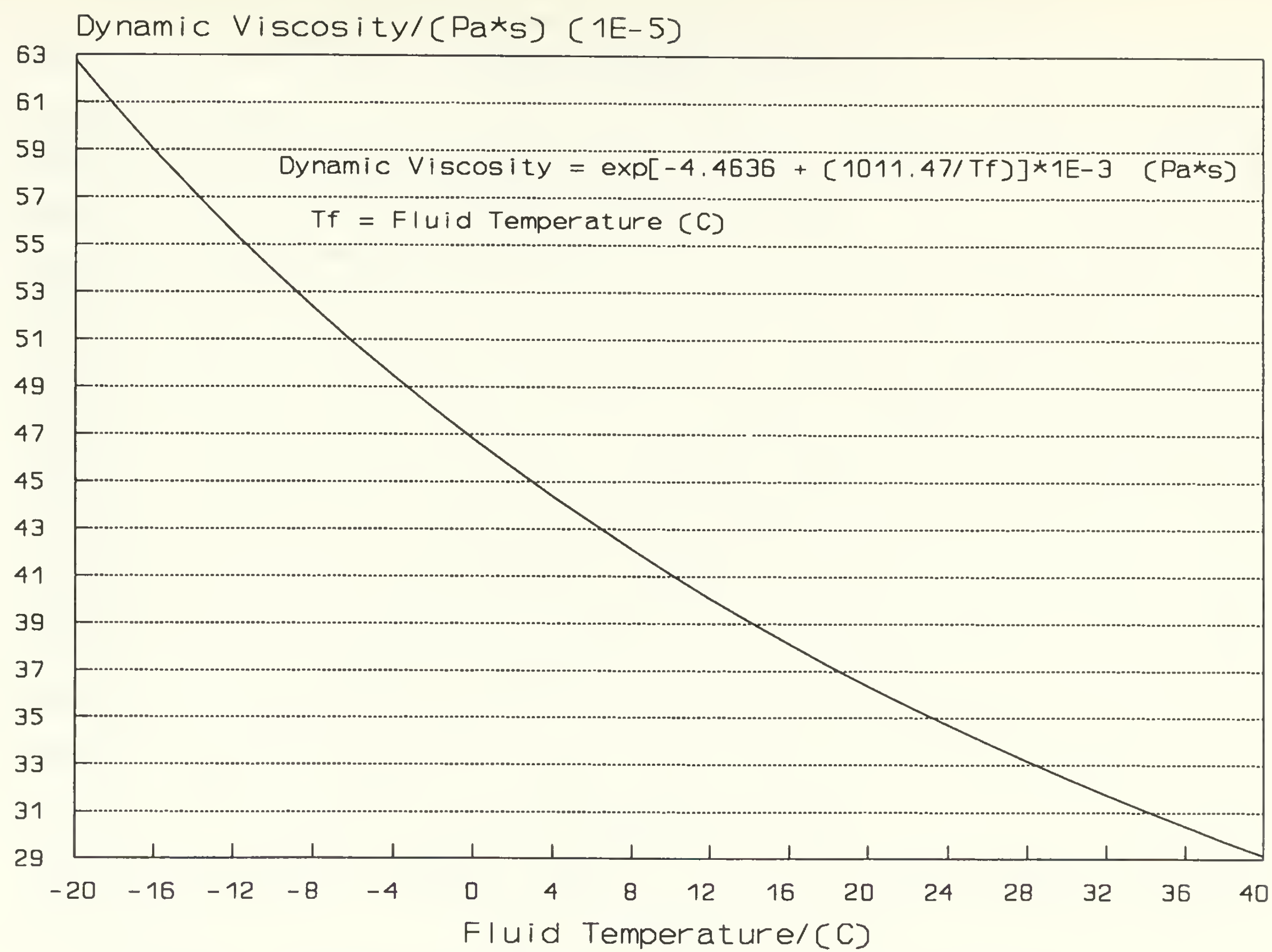


Figure A.2 Dynamic Viscosity of R-114

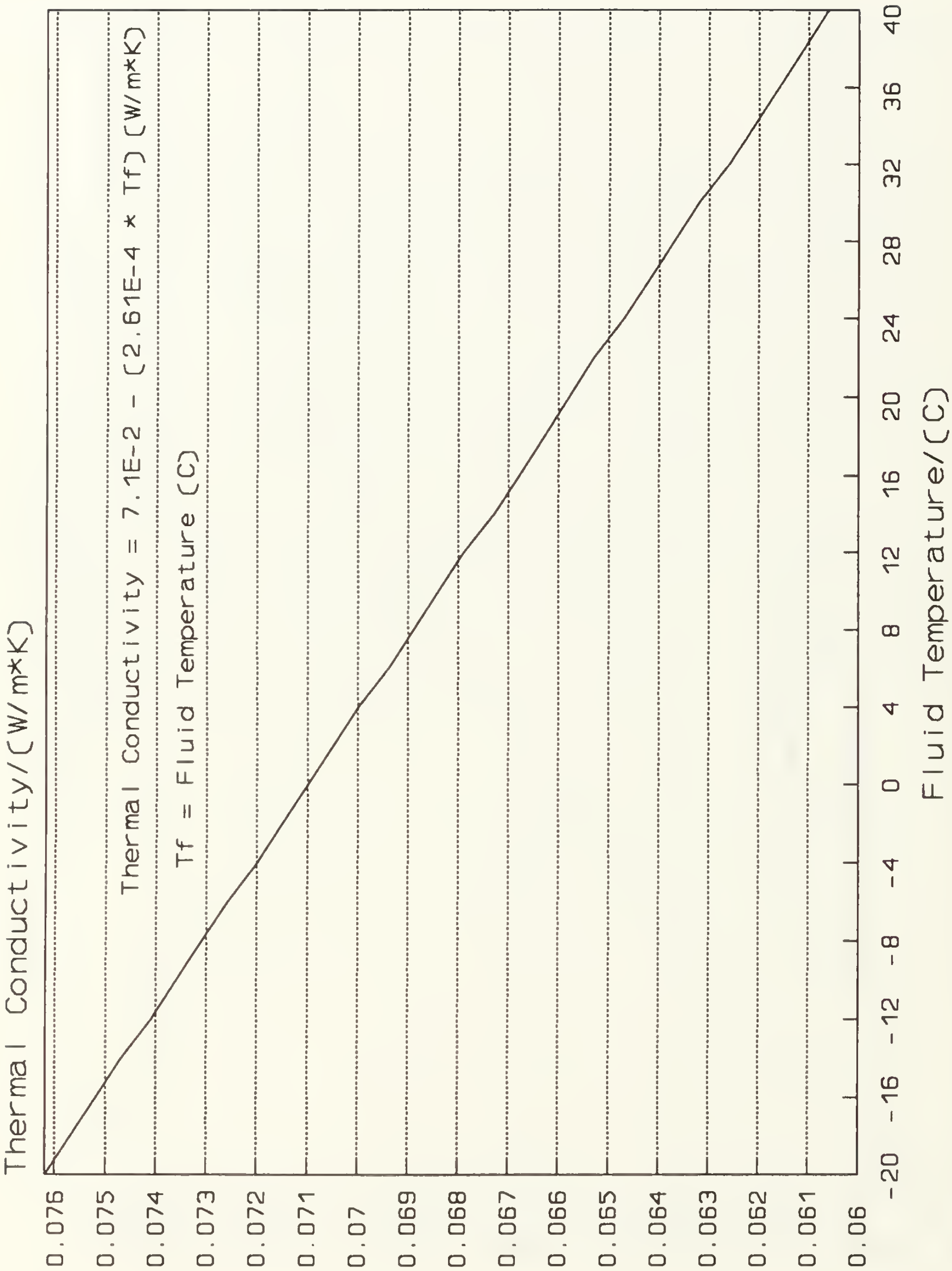


Figure A.3 Thermal Conductivity of R-114

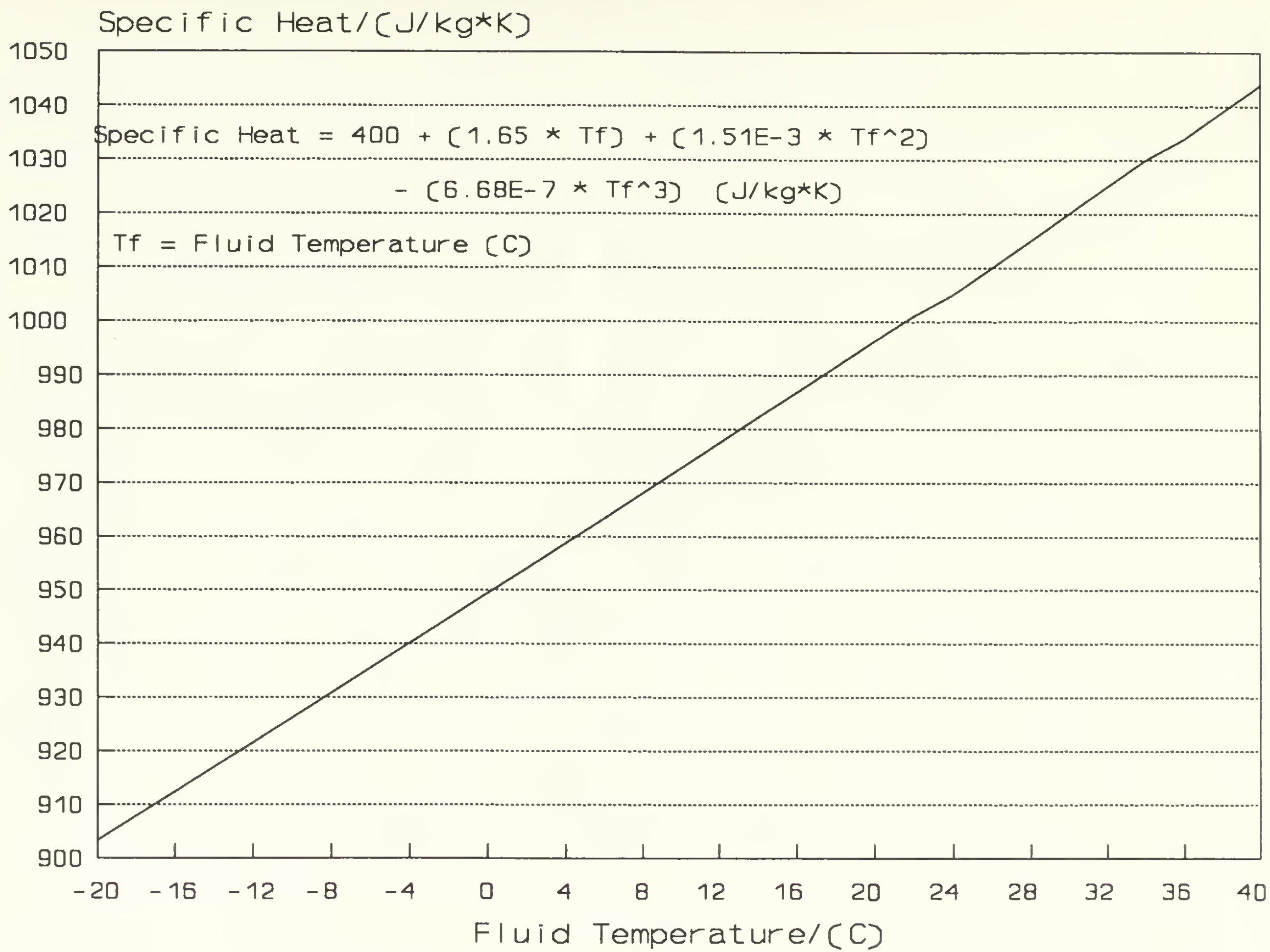


Figure A.4 Specific Heat of R-114

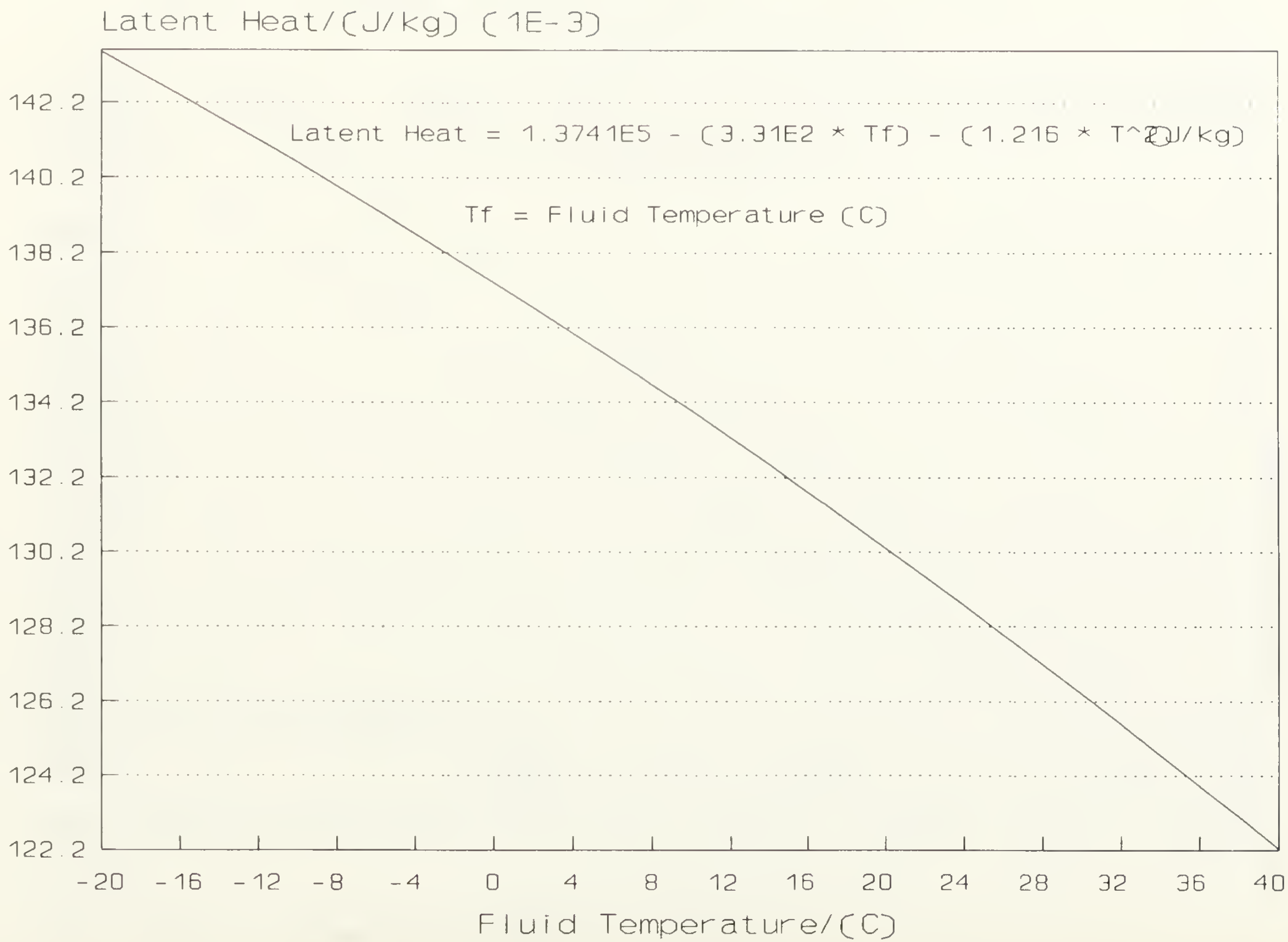


Figure A.5 Latent Heat of R-114

APPENDIX B: DATA ACQUISITION APPARATUS CALIBRATION

A. BACKGROUND

Early data runs revealed a disparity in calculated values between previously reported theses and those presently obtained for heat flux and heat-transfer coefficients. The thermocouple channels were checked for validity of temperature readings using other programs and data acquisition equipment. Their readings were found to be as accurate as possible (± 3%). Voltage readings originating from the RMS converter were also checked out as accurate. The RMS converter converts true voltage measured into a proportional voltage output (0-10 volts) to the data acquisition unit. The proportionality constant to convert RMS voltage readings, Vs, to real tube heater voltage, V, was equal to 25. This was verified using a standard voltmeter across the power leads of the cartridge heater measured over several power settings. The discrepancy was identified to be the measurement of the current supplied to the tube cartridge heater by the VARIAC unit as measured by the inductive pickup (Figure 3.13). The inductive measurement of current (in proportional volts) is no longer run through the RMS converter. Instead, it is run directly to the Data Acquisition Unit. A procedure to measure the true current and calculate the proportionality constant for converting the

inductive current, Is, to the true current, I, was established as follows:

B. EQUIPMENT USED

1. Voltmeter
2. 2 ohm resistor
3. HP-3852A Data Acquisition Unit
4. Computer - HP-9300 Series
5. Current Sensor (Inductive Pickup)
6. Voltage Sensor/RMS Converter
7. Cartridge Heater - 1kW, 220V rating
8. VARIAC - power supply 220V AC
9. SETUP8 program

C. CALIBRATION PROCEDURE

1. Ensure all power is turned off to the VARIAC.
2. Insert the standard 2 ohm resistor in series with the cartridge heater as shown in Figure C.1.
3. Connect leads of voltmeter across the 2 ohm resistor to measure the drop in voltage. At any given power setting, the current through the resistor will equal the current through the cartridge heater. This assumes the resistances of both heater and resistor are constant. This was verified as shown in Figure C.2. The total resistance of the heater/resistor rapidly and asymptotically approached a constant value.
4. Connect power to the VARIAC.
5. Load and run SETUP8 program to provide the voltage and current readings made by the data acquisition unit. Note the SETUP8 program used in calibration differed

from that listed in Appendix G. A proportionality constant of 2.0 was assumed for calibration then modified once the true value was calculated.

6. Starting with the VARIAC set at zero volts, incrementally increase the voltage up to the maximum of 220V.

7. At each voltage, measure the drop in voltage across the resistor. The current (amps) is calculated:

   I = Drop in voltage (volts) / 2 ohms

8. Note and compare the current provided by the program.

9. At the maximum 220V, incrementally decrease voltage down to 0, taking comparative current readings as before, in order to detect any hysteresis effect. None was observed.

10. Plot current (amps) vs. voltage (volts). See Figure C.3. Note the linearity of both data sets. The true meter reading is some factor smaller than the data acquisition readings.

11. The calibration constant, C, is calculated by:

$$C = \frac{(\Sigma \text{ Meter current})}{(\Sigma \text{ Data acquisition current})} * 2$$

   C = 1.9182

D. DISCUSSION

A disparity between the previous reported theses values and those presently obtained still exists. Calculated values reported in previous theses for the heat flux and the heat transfer coefficient are consistently higher. No previous thesis reports such a calibration as carried out above and it is thought that this is the cause of the discrepancy.

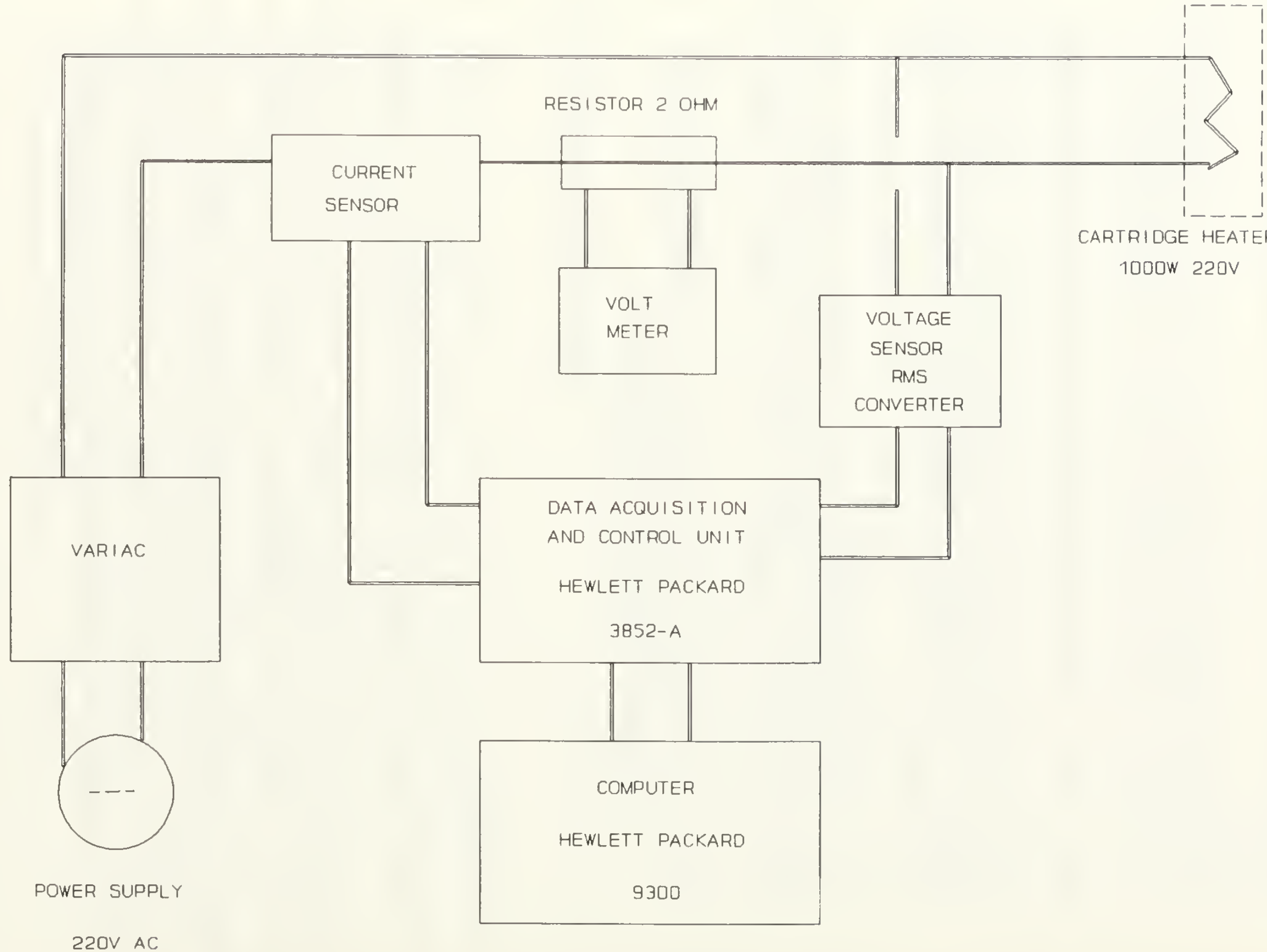


Figure B.1 Schematic of Calibration Setup

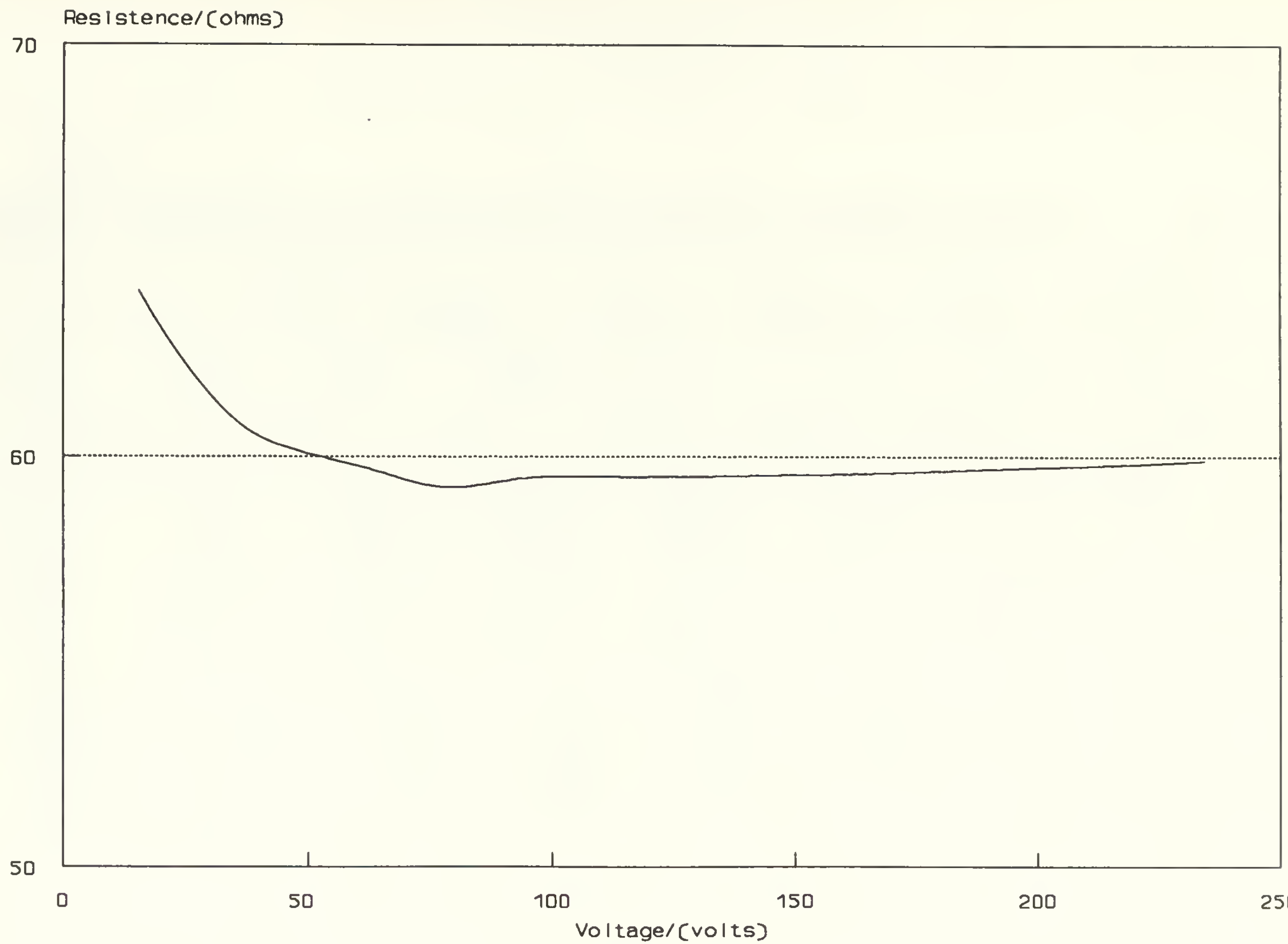


Figure B.2 Cartridge Heater Resistence
For High Flux Tube

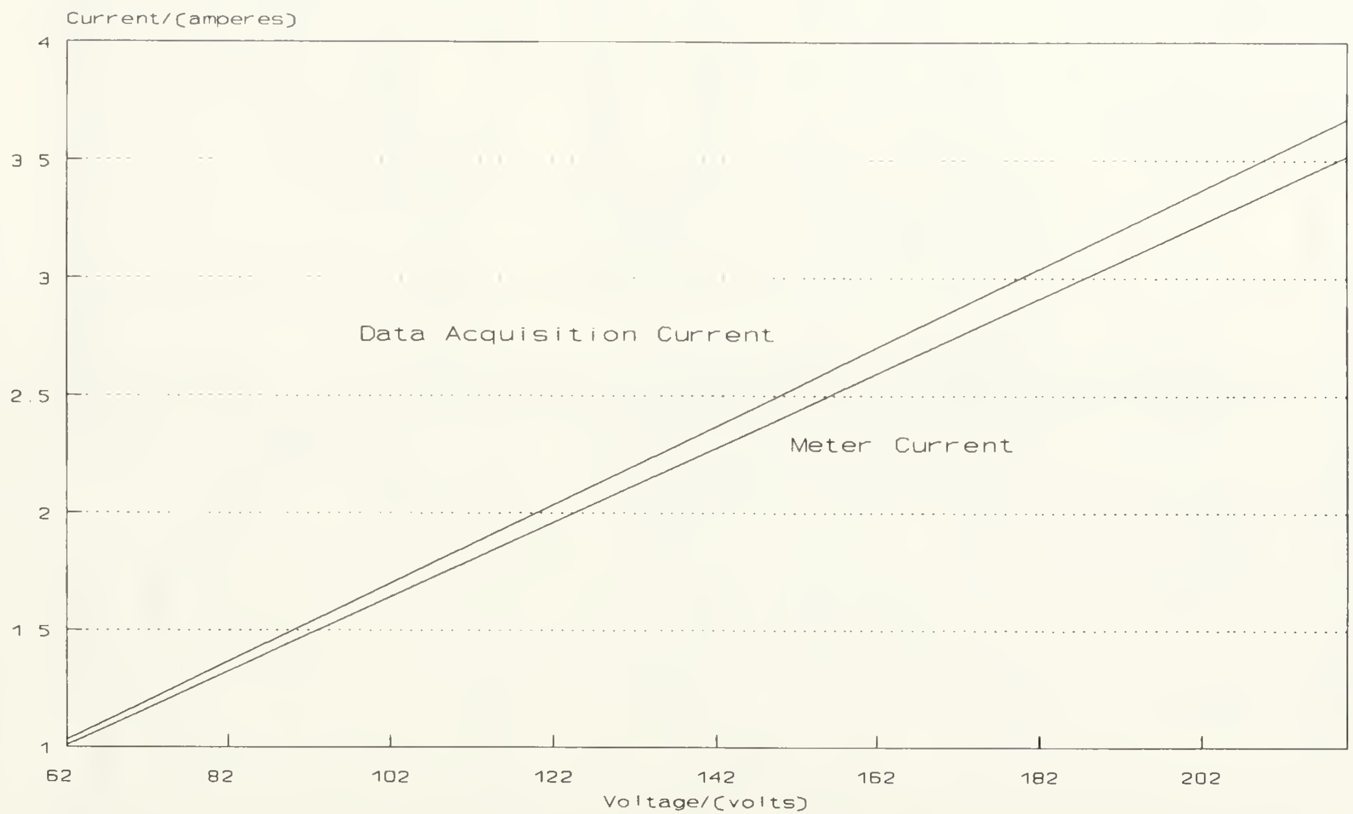


Figure 8.3 Variac Current Calibration
Using High Flux Tube

APPENDIX C: AN EXAMPLE OF REPRESENTATIVE DATA RUN

```
Month, data and time : 5 Jul 1991        17:21:51

NOTE: Program name : DRP8
      Disk number  = 01
      New file name: DATA070515
      TC is defective at location  2
      Tube Number:   5

Data Set Number =   1  Bulk Oil % =  0.0       2.11545538805
TC No:     1      2      3      4      5      6      7      8
Temp :    5.11   0.00   5.15   5.01   5.12   5.08   5.09   5.11
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  5.08   2.36    2.26    3.91  -1.65   -13.8
 Thetab  Htube       Qdp
  2.770  1.590E+02  4.406E+02

Data Set Number =   2  Bulk Oil % =  0.0       2.11545539033
TC No:     1      2      3      4      5      6      7      8
Temp :    4.94   0.00   5.04   4.87   4.99   4.95   4.96   4.98
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  4.95   2.23    2.18    3.29  -1.76   -13.7
 Thetab  Htube       Qdp
  2.740  1.603E+02  4.391E+02

Data Set Number =   3  Bulk Oil % =  0.0       2.11545539756
TC No:     1      2      3      4      5      6      7      8
Temp :    6.08   0.00   6.19   5.96   6.14   6.09   6.11   6.15
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  6.07   2.38    2.16    3.27  -1.69   -13.6
 Thetab  Htube       Qdp
  3.806  1.694E+02  6.446E+02

Data Set Number =   4  Bulk Oil % =  0.0       2.11545539780
TC No:     1      2      3      4      5      6      7      8
Temp :    6.12   0.00   6.23   6.02   6.18   6.14   6.15   6.18
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  6.12   2.39    2.19    3.29  -1.67   -13.6
 Thetab  Htube       Qdp
  3.828  1.682E+02  6.439E+02

Data Set Number =   5  Bulk Oil % =  0.0       2.11545540628
TC No:     1      2      3      4      5      6      7      8
Temp :    7.13   0.00   7.27   6.97   7.24   7.15   7.17   7.25
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  7.13   2.24    2.16    2.92  -1.77   -13.6
 Thetab  Htube       Qdp
  4.934  1.791E+02  8.834E+02

Data Set Number =   6  Bulk Oil % =  0.0       2.11545540655
TC No:     1      2      3      4      5      6      7      8
Temp :    7.09   0.00   7.25   6.95   7.21   7.13   7.15   7.20
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  7.11   2.20    2.12    2.91  -1.81   -13.5
 Thetab  Htube       Qdp
  4.945  1.786E+02  8.834E+02

Data Set Number =   7  Bulk Oil % =  0.0       2.11545541023
TC No:     1      2      3      4      5      6      7      8
Temp :    9.56   0.00   9.74   9.36   9.71   9.60   9.62   9.75
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  9.57   2.47    2.22    2.94  -1.61   -13.5
 Thetab  Htube       Qdp
  7.223  1.863E+02  1.346E+03
```

```
Data Set Number =   8  Bulk Oil % =  0.0       2.11545541165
TC No:     1      2      3      4      5      6      7      8
Temp :    9.33   0.00   9.52   9.11   9.49   9.37   9.39   9.50
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  9.33   2.21     2.13    2.82  -1.80  -13.5
 Thetab  Htube        Qdp
  7.165  1.874E+02  1.343E+03

Data Set Number =   9  Bulk Oil % =  0.0       2.11545541546
TC No:     1      2      3      4      5      6      7      8
Temp :   10.99   0.00  11.53  11.09  11.50  11.38  11.40  11.40
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
 11.26   2.30     2.16    2.66  -1.73  -13.5
 Thetab  Htube        Qdp
  9.026  1.963E+02  1.772E+03

Data Set Number =  10  Bulk Oil % =  0.0       2.11545541589
TC No:     1      2      3      4      5      6      7      8
Temp :   11.00   0.00  11.52  11.09  11.50  11.37  11.40  11.41
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
 11.26   2.32     2.22    2.67  -1.69  -13.5
 Thetab  Htube        Qdp
  8.988  1.977E+02  1.777E+03

Data Set Number =  11  Bulk Oil % =  0.0       2.11545541889
TC No:     1      2      3      4      5      6      7      8
Temp :   11.45   0.00  12.32  11.93  12.30  12.18  12.21  12.10
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
 11.99   2.24     2.17    2.67  -1.76  -13.5
 Thetab  Htube        Qdp
  9.783  2.074E+02  2.029E+03

Data Set Number =  12  Bulk Oil % =  0.0       2.11545541913
TC No:     1      2      3      4      5      6      7      8
Temp :   11.50   0.00  12.38  11.97  12.35  12.24  12.25  12.14
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
 12.04   2.26     2.19    2.69  -1.74  -13.5
 Thetab  Htube        Qdp
  9.814  2.065E+02  2.027E+03

Data Set Number =  13  Bulk Oil % =  0.0       2.11545542290
TC No:     1      2      3      4      5      6      7      8
Temp :   12.08   0.00  13.11  12.71  13.09  12.98  12.99  12.82
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
 12.74   2.22     2.20    2.96  -1.75  -13.5
 Thetab  Htube        Qdp
 10.527  2.112E+02  2.223E+03

Data Set Number =  14  Bulk Oil % =  0.0       2.11545542315
TC No:     1      2      3      4      5      6      7      8
Temp :   12.02   0.00  13.05  12.67  13.03  12.92  12.94  12.75
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
 12.68   2.20     2.17    2.96  -1.78  -13.5
 Thetab  Htube        Qdp
 10.494  2.110E+02  2.214E+03

Data Set Number =  15  Bulk Oil % =  0.0       2.11545542511
TC No:     1      2      3      4      5      6      7      8
Temp :   12.55   0.00  13.83  13.53  13.82  13.72  13.73  13.43
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
 13.42   2.19     2.16    2.92  -1.79  -13.5
 Thetab  Htube        Qdp
 11.239  2.182E+02  2.452E+03
```

```
Data Set Number =  16  Bulk Oil % =  0.0       2.11545542534
TC No:     1       2       3       4       5       6       7       8
Temp :  12.62   0.00  13.85  13.61  13.83  13.75  13.75  13.47
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 13.46    2.26     2.22    2.91   -1.72   -13.5
 Thetab  Htube        Qdp
 11.217  2.183E+02  2.449E+03

Data Set Number =  17  Bulk Oil % =  0.0       2.11545543206
TC No:     1       2       3       4       5       6       7       8
Temp :    2.89   0.00   2.74   2.69   2.69   2.59   2.57   2.68
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  2.58    2.44     2.19    2.01   -1.64   -13.5
 Thetab  Htube        Qdp
   .270  1.126E+04  3.036E+03

Data Set Number =  18  Bulk Oil % =  0.0       2.11545543229
TC No:     1       2       3       4       5       6       7       8
Temp :    2.86   0.00   2.71   2.66   2.67   2.56   2.55   2.65
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  2.56    2.39     2.15    1.98   -1.69   -13.5
 Thetab  Htube        Qdp
   .288  1.052E+04  3.029E+03

Data Set Number =  19  Bulk Oil % =  0.0       2.11545543435
TC No:     1       2       3       4       5       6       7       8
Temp :    3.15   0.00   2.97   2.92   2.92   2.79   2.75   2.91
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  2.76    2.41     2.17    2.09   -1.67   -13.5
 Thetab  Htube        Qdp
   .472  9.576E+03  4.523E+03

Data Set Number =  20  Bulk Oil % =  0.0       2.11545543508
TC No:     1       2       3       4       5       6       7       8
Temp :    3.12   0.00   2.93   2.89   2.89   2.75   2.72   2.88
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  2.73    2.47     2.19    2.08   -1.62   -13.5
 Thetab  Htube        Qdp
   .394  1.144E+04  4.506E+03

Data Set Number =  21  Bulk Oil % =  0.0       2.11545543579
TC No:     1       2       3       4       5       6       7       8
Temp :    3.02   0.00   2.83   2.79   2.79   2.64   2.62   2.77
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  2.62    2.37     2.09    1.98   -1.74   -13.5
 Thetab  Htube        Qdp
   .394  1.149E+04  4.525E+03

Data Set Number =  22  Bulk Oil % =  0.0       2.11545543829
TC No:     1       2       3       4       5       6       7       8
Temp :    3.45   0.00   3.20   3.16   3.15   2.96   2.91   3.14
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  2.89    2.41     2.16    2.76   -1.67   -13.5
 Thetab  Htube        Qdp
   .603  1.178E+04  7.099E+03

Data Set Number =  23  Bulk Oil % =  0.0       2.11545543855
TC No:     1       2       3       4       5       6       7       8
Temp :    3.44   0.00   3.19   3.15   3.14   2.96   2.90   3.13
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  2.88    2.39     2.15    2.87   -1.69   -13.5
 Thetab  Htube        Qdp
   .612  1.158E+04  7.092E+03
```

```
Data Set Number =  24  Bulk Oil % =  0.0      2.11545544709
TC No:    1      2      3      4      5      6      7      8
Temp :   3.95   0.00   3.56   3.55   3.50   3.29   3.20   3.52
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.12   2.36    2.17    2.71  -1.69  -13.6
 Thetab  Htube       Ddo
   .857  1.279E+04  1.096E+04

Data Set Number =  25  Bulk Oil % =  0.0      2.11545544732
TC No:    1      2      3      4      5      6      7      8
Temp :   3.95   0.00   3.56   3.55   3.49   3.28   3.19   3.52
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.12   2.36    2.16    2.75  -1.70  -13.6
 Thetab  Htube       Ddo
   .859  1.279E+04  1.098E+04

Data Set Number =  26  Bulk Oil % =  0.0      2.11545545094
TC No:    1      2      3      4      5      6      7      8
Temp :   4.48   0.00   3.92   3.95   3.85   3.62   3.49   3.92
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.36   2.38    2.19    2.07  -1.67  -13.6
 Thetab  Htube       Ddo
  1.073  1.411E+04  1.514E+04

Data Set Number =  27  Bulk Oil % =  0.0      2.11545545119
TC No:    1      2      3      4      5      6      7      8
Temp :   4.45   0.00   3.89   3.93   3.83   3.60   3.46   3.89
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.33   2.33    2.15    2.04  -1.72  -13.6
 Thetab  Htube       Ddo
  1.092  1.385E+04  1.512E+04

Data Set Number =  28  Bulk Oil % =  0.0      2.11545545460
TC No:    1      2      3      4      5      6      7      8
Temp :   5.12   0.00   4.37   4.43   4.27   4.04   3.86   4.40
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.65   2.35    2.17    2.08  -1.70  -13.6
 Thetab  Htube       Ddo
  1.390  1.437E+04  1.996E+04

Data Set Number =  29  Bulk Oil % =  0.0      2.11545545484
TC No:    1      2      3      4      5      6      7      8
Temp :   5.12   0.00   4.36   4.42   4.26   4.03   3.84   4.39
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  3.64   2.34    2.16    2.07  -1.71  -13.6
 Thetab  Htube       Ddo
  1.393  1.433E+04  1.996E+04

Data Set Number =  30  Bulk Oil % =  0.0      2.11545546220
TC No:    1      2      3      4      5      6      7      8
Temp :   6.47   0.00   5.25   5.39   5.11   4.90   4.58   5.33
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  4.23   2.31    2.18    2.10  -1.72  -13.6
 Thetab  Htube       Ddo
  1.989  1.505E+04  2.993E+04

Data Set Number =  31  Bulk Oil % =  0.0      2.11545546248
TC No:    1      2      3      4      5      6      7      8
Temp :   6.45   0.00   5.23   5.37   5.09   4.88   4.57   5.31
 Twa     Tliqd   Tliqd2  Tvapr  Psat    Tsump
  4.22   2.27    2.15    2.08  -1.75  -13.6
 Thetab  Htube       Ddo
  2.003  1.497E+04  2.998E+04
```

```
Data Set Number =  32  Bulk Oil % =  0.0       2.11545546659
TC No:     1       2       3       4       5       6       7       8
Temp :   8.99   0.00    6.66    6.92    6.39    6.17    5.57    6.63
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  5.16   2.33     2.18    2.13   -1.71   -13.4
 Thetab  Htube        Odp
  2.910  1.559E+04  4.535E+04

Data Set Number =  33  Bulk Oil % =  0.0       2.11545546682
TC No:     1       2       3       4       5       6       7       8
Temp :   8.97   0.00    6.64    6.90    6.37    6.14    5.56    6.62
 Twe     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  5.15   2.30     2.17    2.10   -1.73   -13.3
 Thetab  Htube        Odp
  2.911  1.556E+04  4.531E+04

Data Set Number =  34  Bulk Oil % =  0.0       2.11545546951
TC No:     1       2       3       4       5       6       7       8
Temp :  12.55   0.00    8.98    9.39    8.54    8.06    6.96    8.56
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  6.53   2.29     2.16    2.15   -1.74   -13.2
 Thetab  Htube        Odp
  4.305  1.632E+04  7.028E+04

Data Set Number =  35  Bulk Oil % =  0.0       2.11545546986
TC No:     1       2       3       4       5       6       7       8
Temp :  12.59   0.00    9.01    9.42    8.57    8.09    6.99    8.60
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  6.56   2.31     2.19    2.18   -1.71   -13.2
 Thetab  Htube        Odp
  4.315  1.627E+04  7.019E+04

Data Set Number =  36  Bulk Oil % =  0.0       2.11545547257
TC No:     1       2       3       4       5       6       7       8
Temp :  16.06   0.00   11.35   11.79   10.57   10.04    8.26   10.43
 Twe     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  7.84   2.23     2.15    2.14   -1.77   -12.9
 Thetab  Htube        Odp
  5.649  1.694E+04  9.569E+04

Data Set Number =  37  Bulk Oil % =  0.0       2.11545547281
TC No:     1       2       3       4       5       6       7       8
Temp :  16.11   0.00   11.39   11.81   10.59   10.07    8.28   10.46
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
  7.87   2.26     2.18    2.17   -1.75   -12.8
 Thetab  Htube        Odp
  5.656  1.692E+04  9.572E+04
NOTE: 37 data runs were stored in file DATA0705IS

NOTE: 37 X-Y pairs were stored in plot data file PLOT0705IS
```

APPENDIX D: SAMPLE CALCULATION

Data run number 9 (saturation temperature was 2.22 °C and heat flux was 20.14 kW/m^2) was chosen for the sample calculation.

A. TEST-SECTION DIMENSIONS

$Do = 0.01588$ m
$Di = 0.01270$ m
$D1 = 0.01143$ m
$D2 = 0.01588$ m
$L = 0.20320$ m
$Lu = 0.07620$ m

B. MEASURED PARAMETERS

V	=	112.08 volts
I	=	1.94 volts
T1	=	16.51 °C
T2	=	15.80 °C
T3	=	15.88 °C
T4	=	15.93 °C
T5		not read due to defective thermocouple
T6	=	15.94 °C
T7	=	15.63 °C
T8	=	16.16 °C
Tsat	=	2.22 °C
kc	=	344.00 (W/m·K)

C. OUTER WALL TEMPERATURE OF THE BOILING TUBE

$$p = \pi \cdot Do = 3.1416 \cdot 0.01588 = 0.0499 \text{ (m)}$$
$$Ac = \pi(Do^2 - Di^2)/4 = 3.1416 \cdot [(0.01588)^2 - (0.0127)^2]/4$$
$$Ac = 7.14E-5 \text{ (m}^2\text{)}$$
$$Qh = VI = 112.08 \cdot 1.94 = 217.44 \text{ (W)}$$
$$Tavg = \sum Tn / n = 15.97 \text{ (°C)}$$
$$Two = Tavg - Qh \cdot [\ \ln(D2/D1) / (2 \cdot \pi \cdot L \cdot kc)\ ]$$
$$Two = 15.97 - 217.44 \cdot [\ln(15.88/11.43)/(2 \cdot 3.1416 \cdot 0.203 \cdot 344)]$$

$Two = 15.80\ (^\circ C)$
$\theta = Two - Tsat = 15.80 - 2.22 = 13.58\ ^\circ C$

D. PROPERTIES OF R-114 AT FILM TEMPERATURE

$Tf = (Two+Tsat)/2 = (15.80+2.22)/2 = 9.01\ ^\circ C$
$\mu = \exp[-4.4636 + (1011.47/Tf)] \cdot 1E-3$
$\mu = \exp[-4.4636+(1011.47/9.01)] \cdot 1E-3 = 4.16E-4\ (N\cdot s/m^2)$
$Tc = \text{Critical Temperature (R)} = 753.95\ (R)$
$Tf = 9.01\ (^\circ C) = 507.89\ (R)$
$j = 1 - Tf(R)/Tc(R) = 1 - 507.89/753.95 = 0.33$
$\rho = 581.77 + 984.15\cdot j^{(1/3)} + 263.02\cdot j + 279.99\cdot j^{1/2} + 17.94\cdot j^2\ (kg/m^3)$
$\rho = 1504.22\ (kg/m^3)$
$\nu = \mu/\rho = 4.16E-4/1504.22 = 2.77E-7$
$k = 7.10E-2 - (2.61E-4 \cdot Tf(^\circ C))$
$k = 7.10E-2 - (2.61E-4 \cdot 9.01) = 6.86E-2\ (W/m\cdot K)$
$Tf = 9.01\ (^\circ C) = 282.16\ (K)$
$Cp = 400 + (1.65 \cdot Tf) + (1.51E-3 \cdot Tf^2) - (6.68E-7 \cdot Tf^3)$
$Cp = 970.43\ (J/kg\cdot K)$
$\alpha = k/\rho\cdot Cp = 6.86E-2/(1504.22\cdot 970.43) = 4.7E-8\ (m^2/s)$
$\beta = -(\Delta\rho/\Delta T)/\rho = 1.92E-3\ (1/K)$
$Pr = \nu/\alpha = 5.88$

E. HEAT-FLUX CALCULATION

Average natural-convection heat transfer coefficient at non-boiling ends:

$$h = \frac{k}{Do} \cdot \left\{ 0.60+0.387\cdot \frac{\left(\dfrac{g\cdot \beta\cdot (Do^3)\cdot \theta\cdot \mathrm{Tanh}(m\cdot Lu)}{\nu\cdot \alpha\cdot Lu\cdot m}\right)^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}} \right\}^2$$

$$m = [h\cdot p/(kc\cdot Ac)]^{1/2}$$

$h = 235.4\ (W/m^2\cdot K)$

The value for h was computed iteratively. A value for h of 190 $(W/m^2\cdot K)$ was assumed at start of iteration.

Heat-transfer rate through non-boiling ends:

$m = 21.87\ (1/m)$
$Qf = (h\cdot p\cdot kc\cdot Ac)^{1/2}\cdot \theta\cdot \mathrm{Tanh}(m\cdot Lu) = 6.79\ (W)$

Heat flux through active boiling surface

$$Q = Qh - 2 \cdot Qf = 217.44 - 2 \cdot 6.79 = 203.85 \ (W)$$
$$Ab = \pi \cdot Do \cdot L = 3.1416 \cdot 0.015875 \cdot 0.2032 = 1.01E-2 \ (m^2)$$
$$q'' = Q/Ab = 203.85/1.02E-2 = 20{,}108 \ (W/m^2)$$
$$h = q/\theta = 20{,}108/13.59 = 1480 \ (W/m^2 \cdot K)$$

The following are the results obtained from the computer by running the data reduction program DRP8 (See Appendix H).

$$q'' = 20{,}140 \ (W/m^2)$$
$$\theta = 13.64 \ (^\circ C)$$
$$h = 1477 \ (W/m^2 \cdot K)$$

TABLE IV. DIMENSIONS OF BOILING TUBES

	D1 (mm)	D2 (mm)	Di (mm)	Do (mm)	L (mm)	Lu (mm)	Kcu $\frac{(W)}{m^2 \cdot K}$
Smooth	12.44	15.88	12.70	15.88	203.2	76.20	344
GEWA-K 26 fpi	10.1	12.7	11.11	12.7	203.2	76.2	398
GEWA-K 40 fpi	10.1	12.7	11.11	12.7	203.2	76.2	398
GEWA-T 19 fpi	11.57	13.8	11.8	13.31	203.2	76.2	398
GEWA-T 26 fpi	11.57	13.8	11.8	13.31	203.2	76.2	398
GEWA-YX 26 fpi	11.57	13.8	11.8	13.31	203.2	76.2	398
Thermoexcel-E	11.57	13.8	11.8	13.31	203.2	76.2	398
Thermoexcel-HE	11.57	13.8	11.8	13.31	203.2	76.2	398
Turbo-B	11.57	13.8	11.8	15.8	203.2	76.2	398
High Flux (Copper/ Nickel 95/5)	12.95	15.82	13.2	15.82	203.2	76.2	45

APPENDIX E: UNCERTAINTY ANALYSES

Four data points from two data runs were chosen for the uncertainty analysis: data run number 8 (smooth tube, 0% oil, 100,000 & 3500 W/m^2) and data run number 74 (Thermoexcel-E, 0% oil, 6000 & 100,000 W/m^2. The dimensions of the boiling tubes can be found in Appendix D, Table IV. The measured and calculated parameters used in this analysis were obtained as shown in Appendix D and are listed in Table V of this appendix. All uncertainties are presented as a percentage of the calculated parameter. What follows is a sample calculation for data run number 8: smooth tube, 0% oil at a heat flux of 93,130 W/m^2 using the methods outlined by Kline and McClintock [Ref. 17]. All other data point uncertainties were calculated similarly, the results of which are listed in Table V of this appendix.

A. UNCERTAINTY IN SOURCE HEAT-TRANSFER RATE

$Qh = VI$ W
$Is = 2.122$ volts $\qquad \delta I = \pm 0.025$ amp
$Vs = 9.45$ volts $\qquad \delta V = \pm 0.05$ volts
$I = 1.9182 \cdot Is = 4.07$ amp
$V = 25 \cdot Vs = 236.26$ volts

where:

δ = uncertainty in measurement and calculation

$$\delta Qh/Qh = ((\delta V/Vs)^2 + (\delta I/Is)^2)^{1/2}$$
$$\delta Qh/Qh = ((0.05/9.45)^2 + (0.025/2.122)^2)^{1.2}$$
$$\delta Qh/Qh = 1.29 \text{ percent}$$

B. UNCERTAINTY IN SURFACE AREA

$Ab = \pi \cdot Do \cdot L$

$Do = 15.88$ (mm) $\qquad \delta Do = 0.1$ (mm)

$L = 203.20$ (mm) $\qquad \delta L = 0.1$ (mm)

$$\delta Ab/Ab = ((\delta Do/Do)^2 + (\delta L/L)^2)^{1/2}$$
$$\delta Ab/Ab = ((0.1/15.88)^2 + (0.1/203.2)^2)^{1/2}$$
$$\delta Ab/Ab = 0.63 \text{ percent}$$

C. UNCERTAINTY IN WALL SUPERHEAT

$\Delta T = Two - Tsat$

$Tsat = 2.22$ °C $\qquad \delta T = 0.01$ °C

$Two = Tavg - Qh[(\ln(D2/D1))/(2 \cdot \pi \cdot L \cdot kc)]$

$Tavg = (\Sigma Tn/8)$ where n = 1 to 8

Tn = thermocouple readings

T1 = 23.86 °C	T2 = 19.62 °C	T3 = 20.38 °C
T4 = 19.87 °C	T5 = Defective thermocouple	
T6 = 20.18 °C	T7 = 20.16 °C	T8 = 20.20 °C

$Tavg = 20.18$ °C

$S.D. = ((\Sigma(Tn - Tavg)^2)/7)^{1/2} = 0.19$ °C
where S.D. = standard deviation

The logarithmic term in equation of Two is very small compared to the standard deviation, this term can be neglected for the uncertainty analysis.

$Two = Tavg = 18.72$ °C $\qquad \delta Two = S.D. = 0.19$ °C

$\Delta T = 17.96$ °C

$$\delta\Delta T/\Delta T = ((\delta Two/\Delta T)^2 + (-\delta Tsat/\Delta T)^2)^{1/2}$$
$$\delta\Delta T/\Delta T = ((0.93/16.5)^2 + (0.01/16.5)^2)^{1/2}$$
$$\delta\Delta T/\Delta T = 1.06 \text{ percent}$$

D. UNCERTAINTY IN HEAT FLUX

$q = (Qh-2Qf)/Ab$

$Qh = 961.58$ W $\qquad \delta Qh = 12.42$ W

Assuming the same proportion in the uncertainty for Qf:

$Qf = 8.99\ W \qquad \delta Qf = 0.12\ W$

$Qh - 2Qf = 943.6\ W$

$$\delta q/q = [(\delta Qh/(Qh-2Qf))^2 + (2\delta Qf/(Qh-2Qf))^2) + (\delta Ab/Ab)^2)]^{1/2}$$
$$\delta q/q = [(12.42/943.6)^2 + (0.24/943.6)^2 + (0.0063)^2]^{1/2}$$
$$\delta q/q = 1.46 \text{ percent}$$

E. UNCERTAINTY IN BOILING HEAT-TRANSFER COEFFICIENT

$h = q/\Delta T$

$$\delta h/h = [(\delta q/q)^2 + (\delta\Delta T/\Delta T)^2]^{1/2}$$
$$\delta h/h = [(0.0146)^2 + (0.01.06)^2]^{1/2}$$
$$\delta h/h = 1.8 \text{ percent}$$

TABLE V. UNCERTAINTY ANALYSIS OF FOUR DATA POINTS

PARAMETERS	SMOOTH 100 kW/m^2	SMOOTH 3500 W/m^2	THERMO-E 6000 W/m^2	THERMO-E 100 kW/m^2
Is (amp)	2.122	0.454	0.494	2.06
Vs (volts)	9.45	2.09	2.20	8.88
I (amp)	4.07	0.90	0.98	3.95
δI (amp)	0.025	0.025	0.025	0.025
V (volts)	236.26	52.29	55.28	222.05
δV (volts)	0.05	0.05	0.05	0.05
Qh (W)	961.58	47.06	54.17	877.1
δQh (W)	12.42	2.83	3.00	7.43
δQh/Qh (%)	1.29	6.00	5.55	0.85
Do (mm)	15.88	15.88	13.31	13.31
δDo (mm)	0.1	0.1	0.1	0.1
L (mm)	203.2	203.2	203.2	203.2
δL (mm)	0.1	0.1	0.1	0.1
Ab (m^2)	1.014E-2	1.014E-2	8.50E-3	8.50E-3
δAb/Ab (%)	0.63	0.63	0.75	0.75
δTsat (°C)	0.01	6.0[illegible]	0.01	2.91
Two (°C)	20.18	12.92	2.77	11.13
δTwo (°C)	0.19	0.28	8.53E-2	0.36
ΔT (°C)	17.96	10.70	0.53	9.80
$\delta\Delta$T/ΔT (%)	1.06	2.62	16.20	3.67
Qf (W)	8.99	5.02	5.69	2.91
δQf	0.12	0.03	0.15	2.48E-2
Qh-2Qf (W)	943.60	37.02	54.06	871.3
q (W/m^2)	93,081	3664	6109	102,542
δq/q (%)	1.46	7.67	5.63	1.14
h (W/m^2•K)	5182	342.4	11,200	10,463
δh/h (%)	1.80	8.10	17.15	3.84

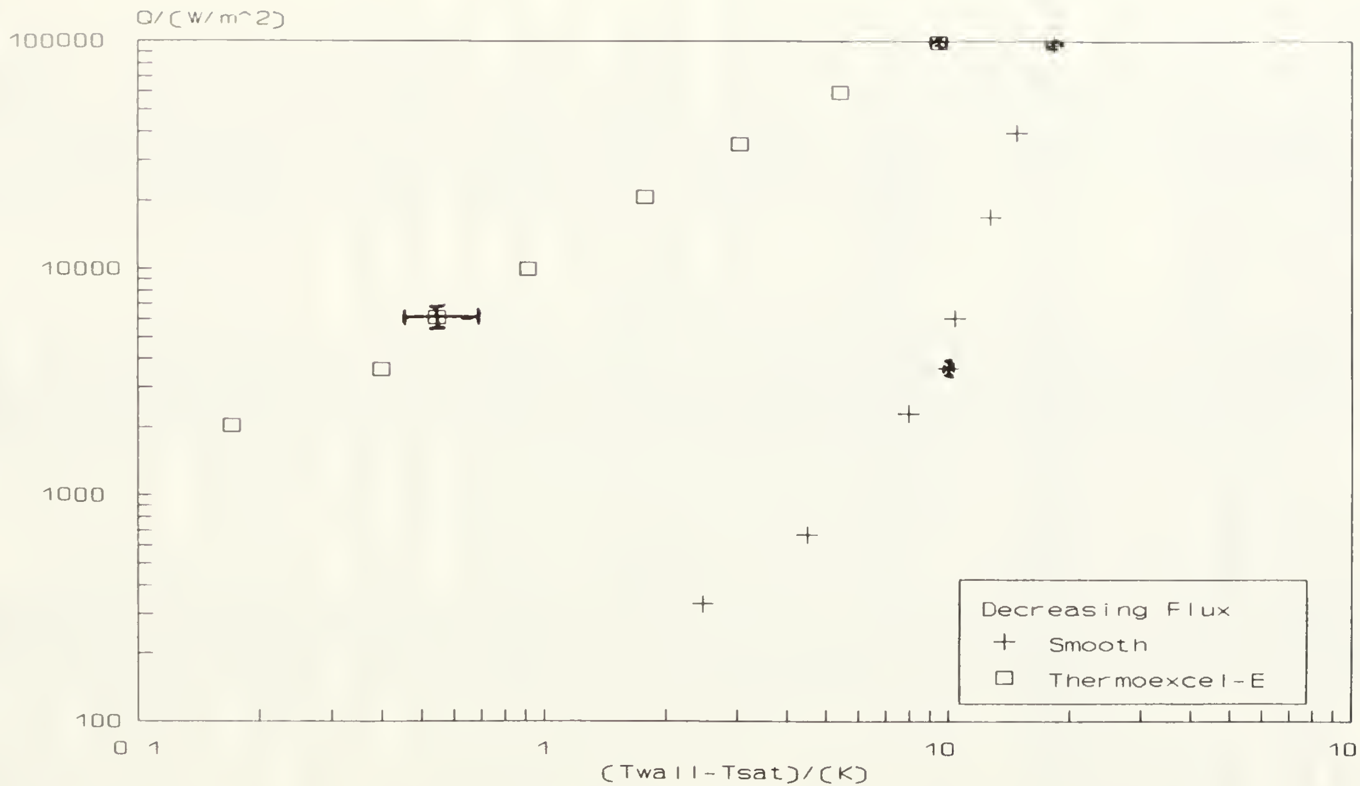


Figure E.1 Uncertainty Analysis
Error Bands for Heat Flux and Superheat

APPENDIX F: SETUP PROGRAM

The following is a listing of the complete setup program used in the preparation of the apparatus for testing. It consists of five sections:

1. Monitor the Sump temperature
2. Monitor the evaporator liquid temperature
3. Measurement and readout of all thermocouple channels.
4. Measurement and readout of the power supplied to the tube cartridge heater.
5. Measurement and readout of the power supplied to the auxilliary heaters if used.

The program was written in Hewlett-Packard Basic 5.0 for both the Hewlett-Packard 9300 series computer and 9852A series data acquisition/control unit.

```
1 !    PROGRAM: SETUP PROGRAM FOR HP 3852A
2 !    DATE:  AUGUST 13,1991
3 !    PROGRAMMER: LT DEAN SUGIYAMA
13     REAL T(0:12),Sum(0:12),Temp(0:12),E(1:3)
23     ON KEY 0,15 GOTO 27
25     PRINTER IS 1
27     PRINT
28     PRINT
30     PRINT USING "4X,""SELECT OPTION"""
31     PRINT USING "6X,""0=MONITOR SUMP"""
32     PRINT USING "6X,""1=MONITOR LIQUID"""
33     PRINT USING "6X,""2=CHECK THERMOCOUPLES"""
34     PRINT USING "6X,""3=CHECK MAIN HEATER"""
35     PRINT USING "6X,""4=CHECK AUX HEATERS"""
36     PRINT USING "6X,""5=EXIT PROGRAM"""
37     PRINT USING "4X,""NOTE: KEY 0 = ESCAPE"""
38     BEEP
40     INPUT Ido
41     IF Ido>5 THEN Ido=5
42     IF Ido=0 THEN 50
43     IF Ido=1 THEN 155
44     IF Ido=2 THEN 185
45     IF Ido=3 THEN 209
46     IF Ido=4 THEN 209
47     IF Ido=5 THEN 252
48     PRINT
49!
50     PRINT
51     PRINT "SUMP TEMPERATURE DEG C "
53     PRINT
54     OUTPUT 709;"RST"
55     Tot=0
56     FOR J=1 TO 5
60     OUTPUT 709;"CONFMEAS TEMPT,511,USE 600"
90     ENTER 709;A
100    Tot=Tot+A
110    NEXT J
120    Tavg=Tot/5
140    PRINT USING "4X,MDD.DD";Tavg
141    BEEP
142    PRINT
150    WAIT 60
151    GOTO 50
152!
155    PRINT
156    PRINT "LIQUID TEMPERATURE DEG C"
158    PRINT
159    OUTPUT 709;"RST"
160    FOR I=1 TO 2
162    Sum(I)=0
163    T(I)=0
165    NEXT I
166    FOR J=1 TO 5
167    OUTPUT 709;"CONFMEAS TEMPT,508-509,USE 600"
168    FOR I=1 TO 2
169    ENTER 709;T(I)
170    Sum(I)=Sum(I)+T(I)
171    NEXT I
172    NEXT J
173    FOR I=1 TO 2
```

```
174   Temp(I)=Sum(I)/5
175   NEXT I
176   Tavg=(Temp(1)+Temp(2))/2
180   PRINT USING "4X,MDD.DD";Tavg
181   BEEP
182   WAIT 60
183   GOTO 155
184 !
185   PRINT
186   PRINT "CHANNEL      TEMPERATURE DEG C"
187   OUTPUT 709;"RST"
188   FOR I=1 TO 12
189   Sum(I)=0
190   T(I)=0
192   NEXT I
193   FOR J=1 TO 5
194   OUTPUT 709;"CONFMEAS TEMPT,500-511,USE 600"
195   FOR I=1 TO 12
196   ENTER 709;T(I)
197   Sum(I)=Sum(I)+T(I)
198   NEXT I
200   NEXT J
201   FOR I=1 TO 12
202   Temp(I)=Sum(I)/5
203   PRINT TAB(3);I;TAB(15);Temp(I)
204   NEXT I
205   BEEP
206   WAIT 5
207   GOTO 185
208 !
209   PRINT
210   OUTPUT 709;"RST"
211   FOR I=1 TO 3
212   Sum(I)=0
215   NEXT I
216   FOR J=1 TO 5
218   OUTPUT 709;"CONFMEAS DCV,512-514,USE 600"
219   FOR I=1 TO 3
221   ENTER 709;E(I)
222   Sum(I)=Sum(I)+E(I)
223   NEXT I
225   NEXT J
226   Amp=0
228   FOR I=1 TO 3
229   IF I=1 THEN Volt=Sum(I)/5
230   IF I=2 AND Ido=3 THEN
231   PRINT "MAKE SURE VOLTAGE BOX IS SET TO MAIN HEATERS"
232   Amp=Sum(I)/5
233   END IF
234   IF I=3 AND Ido=4 THEN
235   PRINT "MAKE SURE VOLTAGE BOX IS SET TO AUX HEATERS"
236   Amp=Sum(I)/5
237   END IF
238   NEXT I
239   Amp=ABS(Amp*1.9182)
240   Volt=ABS(Volt*25)
241   Power=Volt*Amp
242   Resistence=Volt/Amp
243   IF Amp=0 THEN Resistence=0
245   PRINT
```

```
246   BEEP
247   PRINT "    VOLTAGE(V)   CURRENT(A)   RESISTENCE(ohms)   POWER(W)"
248   PRINT
249   PRINT USING "1X,5(MDDDDDD.DDD,3X)";Volt,Amp,Resistence,Power
250   WAIT 5
251   GOTO 209
252   BEEP
253   PRINT
254   PRINT
255   END
```

APPENDIX G: DATA REDUCTION PROGRAM

The following is a listing of the complete data-reduction program, DRP8, written in Hewlett-Packard Basic 5.0 for both the Hewlett-Packard 9300 series computer and 9852A series data acquisition/control unit.

```
1000! FILE NAME: DRP8
1004! DATE:       October 19, 1984
1008! REVISED:    August 14,1991 by LT Dean Sugiyama
1012!
1016  COM /Idp/ Idp
1020  PRINTER IS 1
1024  CALL Select
1028  INPUT "WANT TO SELECT ANOTHER OPTION (1=Y,0=N)?",Isel
1032  IF Isel=1 THEN GOTO 1024
1036  BEEP
1040  BEEP
1044  PRINTER IS 1
1048  PRINT "DATA COLLECTION/REPROCESSING COMPLETED"
1052  END
1056  SUB Main
1060  COM /Idp/ Idp
1064  COM /Cc/ C(7),Ical
1068  COM /Wil/ D2,Di,Do,L,Lu,Kcu
1072  DIM Emf(12),T(12),D1a(13),D2a(13),Dia(13),Doa(13),La(13),Lua(13),Kcua(13),
Et1(20),Et2(20),Tn$(4)[15],Sum(20),Tt(12),Ta(12),Vt(2),Va(2),Eliq(12),E(12)
1076  DATA 0.10086091,25727.94369,-767345.8295,78025595.81
1080  DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
1084  READ C(*)
1088! DATA "Smooth","High Flux","Thermoexel-E","Thermoexel-HE"
1092  DATA Smooth,High Flux,Turbo-B,High Flux Mod,Turbo-B Mod
1096  READ Tn$(*)
1100  PRINTER IS 701
1104  BEEP
1108  IF Idp=4 THEN PRINTER IS 1
1112  IF Idp=4 THEN GOTO 2032
1116  OUTPUT 709;"RST"
1120  OUTPUT 709;"SET TIMEDATE";TIMEDATE
1124  OUTPUT 709;"TIMEDATE"
1128  ENTER 709;Dt
1132  PRINT
1136  PRINT "          Month, date and time :";DATE$(Dt),TIME$(Dt)
1140  PRINT
1144  PRINT USING "10X,""NOTE: Program name : DRP8"""
1148  BEEP
1152  INPUT "ENTER DISK NUMBER",Dn
1156  PRINT USING "16X,""Disk number  = "",ZZ";Dn
1160  BEEP
1164  INPUT "ENTER INPUT MODE (0=3852A,1=FILE)",Im
1168  BEEP
1172  INPUT "SELECT HEATING MODE (0=ELEC; 1=WATER)",Ihm
1176  BEEP
1180  INPUT "ENTER THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
1184  IF Im=0 THEN
1188  BEEP
1192  INPUT "GIVE A NAME FOR THE RAW DATA FILE",D2_file$
1196  PRINT USING "16X,""New file name: "",14A";D2_file$
1200  Size1=20
1204  CREATE BDAT D2_file$,Size1
1208  ASSIGN @File2 TO D2_file$
1212!
1216! DUMMY FILE UNTIL Nrun KNOWN
1220  D1_file$="DUMMY"
1224  CREATE BDAT D1_file$,Size1
1228  ASSIGN @File1 TO D1_file$
```

```
1232  OUTPUT @File1;Dt
1236  IF Ihm=0 THEN
1240  BEEP
1244  INPUT "ENTER NUMBER OF DEFECTIVE TCS (0=DEFAULT)",Idtc
1248  IF Idtc=0 THEN
1252  Ldtc1=0
1256  Ldtc2=0
1260  PRINT USING "16X,""No defective TCs exist"""
1264  END IF
1268  IF Idtc=1 THEN
1272  BEEP
1276  INPUT "ENTER DEFECTIVE TC LOCATION",Ldtc1
1280  PRINT USING "16X,""TC is defective at location "",DD";Ldtc1
1284  Ldtc2=0
1288  END IF
1292  IF Idtc=2 THEN
1296  BEEP
1300  INPUT "ENTER DEFECTIVE TC LOCATIONS",Ldtc1,Ldtc2
1304  PRINT USING "16X,""TC are defective at locations "",DD,4X,DD";Ldtc1,Ldtc2
1308  END IF
1312  IF Idtc>2 THEN
1316  BEEP
1320  PRINTER IS 1
1324  BEEP
1328  PRINT "INVALID ENTRY"
1332  PRINTER IS 701
1336  GOTO 1240
1340  END IF
1344  END IF
1348  OUTPUT @File1;Ldtc1,Ldtc2
1352! Im=1 option
1356  ELSE
1360  BEEP
1364  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D2_file$
1368  PRINT USING "16X,""Old file name: "",14A";D2_file$
1372  ASSIGN @File2 TO D2_file$
1376  ENTER @File2;Nrun
1380  ENTER @File2;Dt
1384  PRINT USING "16X,""This data set taken on : "",11A";DATE$(Dt)
1388  ENTER @File2;Ldtc1,Ldtc2
1392  IF Ldtc1>0 OR Ldtc2>0 THEN
1396  PRINT USING "16X,""Thermocouples were defective at locations:"",2(3D,4X)";
Ldtc1,Ldtc2
1400  END IF
1404  ENTER @File2;Itt
1408  END IF
1409  Idtc=0
1411  IF Ldtc1>0 THEN Idtc=Idtc+1
1412  IF Ldtc2>0 THEN Idtc=Idtc+1
1413! IF Im=0 AND Ihm=1 THEN 1595
1416  BEEP
1420  INPUT "WANT TO CREATE A PLOT FILE? (0=N,1=Y)",Iplot
1424  IF Iplot=1 THEN
1428  BEEP
1432  INPUT "GIVE NAME FOR PLOT FILE",P_file$
1436  CREATE BDAT P_file$,4
1440  ASSIGN @Plot TO P_file$
1444  END IF
1448  IF Ihm=1 THEN
1452  BEEP
```

```
1456  INPUT "WANT TO CREATE Uo FILE? (0=N,1=Y)",Iuf
1460  IF Iuf=1 THEN
1464  BEEP
1468  INPUT "ENTER Uo FILE NAME",Ufile$
1472  CREATE BDAT Ufile$,4
1476  ASSIGN @Ufile TO Ufile$
1480  END IF
1484  BEEP
1488  INPUT "WANT TO CREATE Re FILE? (0=N,1=Y)",Ire
1492  IF Ire=1 THEN
1496  BEEP
1500  INPUT "ENTER Re FILE NAME",Refile$
1504  CREATE BDAT Refile$,10
1508  ASSIGN @Refile TO Refile$
1512  END IF
1516  END IF
1520  PRINTER IS 1
1524  IF Im=0 THEN
1528  BEEP
1532  PRINT USING "4X,""Select tube number"""
1536  IF Ihm=0 THEN
1540  PRINT USING "6X,""0  Smooth 4 inch Ref"""
1544  PRINT USING "6X,""1  Smooth 4 inch Cu (Press/Slide)"""
1548  PRINT USING "6X,""2  Soft Solder 4 inch Cu"""
1552  PRINT USING "6X,""3  Soft Solder 4 inch HIGH FLUX"""
1556  PRINT USING "6X,""4  Wieland Hard 8 inch"""
1560  PRINT USING "6X,""5  HIGH FLUX 8 inch"""
1564  PRINT USING "6X,""6  GEWA-K 40 Fins/in"""
1568  PRINT USING "6X,""7  GEWA-K 26 Fins/in"""
1572  PRINT USING "6X,""8  GEWA-T 19 Fins/in"""
1576  PRINT USING "6X,""9  GEWA-T OR GEWA-TY 26 Fins/in"""
1580  PRINT USING "6X,""10 THERMOEXCEL-E"""
1584  PRINT USING "6X,""11 THERMOEXCEL-HE"""
1585  PRINT USING "6X,""12 TURBO-B"""
1586  PRINT USING "6X,""13 GEWA-K 19 Fins/in"""
1588  ELSE
1592  PRINT USING "6X,""0  Smooth tube"""
1596  PRINT USING "6X,""1  High Flux"""
1600  PRINT USING "6X,""2  Turbo-B"""
1604  PRINT USING "6X,""3  High Flux Mod"""
1608  PRINT USING "6X,""4  Turbo-B Mod"""
1612  END IF
1616  INPUT Itt
1620  OUTPUT @File1;Itt
1624  END IF
1628  PRINTER IS 701
1632  IF Itt<10 THEN PRINT USING "16X,""Tube Number:    "",D";Itt
1636  IF Itt>9 THEN PRINT USING "16X,""Tube Number:    "",DD";Itt
1640  IF Ihm=1 THEN PRINT USING "16X,""Tube Type:      "",15A";Tn$(Itt)
1644  BEEP
1648  INPUT "ENTER OUTPUT VERSION (0=LONG,1=SHORT,2=NONE)",Iov
1652  BEEP
1656  INPUT "SELECT (0=LIQ,1=VAP,2=(LIQ+VAP)/2)",Ilqv
1660!
1664! DIMENSIONS FO TESTED TUBES
1668! ELECTRIC HEATED MODE
1672! Di=Diameter at thermocouple positions
1676  DATA .0111125,.0111125,.0111125,.0129540,.012446,.0129540,.0100965
1680  DATA .0100965,.01157,.01157,.01157,.01157,.01157,.0100965
1684  READ Dia(*)
```

```
1688  D1=D1a(Itt)
1692!
1696! D2=Diameter of test section to the base of fins
1700  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270
1704  DATA .0127,.0138,.0138,.0138,.0138,.0138,.0127
1708  READ D2a(*)
1712!
1716! Di=Inside diameter of unenhanced ends
1720  DATA .0127,.0127,.0127,.0132,.0127,.0132,.0111125,.0111125
1721  DATA .0118,.0118,.0118,.0118,.0118,.0111125
1724  READ Dia(*)
1728!
1732! Do=Outside diameter of unenhanced ends
1736  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270,.01270
1737  DATA .01331,.01331,.01331,.01331,.0158,.0127
1740  READ Doa(*)
1744!
1748! L=Length of enhanced surface
1752  DATA .1016,.1016,.1016,.1016,.2032,.2032,.2032,.2032,.2032,.2032,.2032,.20
32,.2032,.2032
1756  READ La(*)
1760!
1764! Lu=Length of unenhanced surface at the ends
1768  DATA .0254,.0254,.0254,.0254,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.07
62,.0762,.0762
1772  READ Lua(*)
1776!
1780! Kcu=Thermal Conductivity of tube
1784  DATA 398,344,344,45,344,45,344,344,398,398,398,398,398,344
1788  READ Kcua(*)
1792  IF Ihm=1 THEN
1796!
1800! Data statements for water heating mode
1804!
1808  DATA 0.015875,0.015875,0.0169,0.0138,0.0169,0,0,0,0,0
1812  READ D2a(*)
1816  DATA 0.0127,0.0127,0.0145,0.0127,0.0145,0,0,0,0,0
1820  READ Dia(*)
1824  DATA 0.015875,0.015875,0.0169,0.015875,0.0169,0,0,0,0,0
1828  READ Doa(*)
1832  DATA 0.3048,0.3048,0.3048,0.3048,0.3048,0,0,0,0,0
1836  READ La(*)
1840  DATA 0.0254,0.0254,0.0254,0.0254,0.0254,0,0,0,0,0
1844  READ Lua(*)
1848  DATA 398,45,398,45,398,0,0,0,0,0
1852  READ Kcua(*)
1856  END IF
1860  D2=D2a(Itt)
1864  Di=Dia(Itt)
1868  Do=Doa(Itt)
1872  L=La(Itt)
1876  Lu=Lua(Itt)
1880  Kcu=Kcua(Itt)
1884  Xn=.8
1888  Fr=.3
1892  IF Itt=0 THEN Cf=1.70E+9
1896  IF Itt>0 THEN Cf=3.7037E+10
1900  A=PI*(Do^2-Di^2)/4
1904  P=PI*Do
1908  IF Ihm=1 THEN
```

```
1912  BEEP
1916  INPUT "TUBE INITIATION MODE. (1=HOT WATER,2=STEAM,3=COLD WATER)",Itim
1920  IF Itim=1 THEN PRINT USING "16X,""Tube Initiate: Hot Water"""
1924  IF Itim=2 THEN PRINT USING "16X,""Tube Initiate: Steam"""
1928  IF Itim=3 THEN PRINT USING "16X,""Tube Initiate: Cold Water"""
1932  INPUT "TEMP/VEL MODE: (0=T-CONST,V-DEC;1=T-DEC,V-CONST; 2=T-INC,V-CONST)",
Itv
1936  IF Itv=0 THEN PRINT USING "16X,""Temp/Vel Mode: Constant/Decreasing"""
1940  IF Itv=1 THEN PRINT USING "16X,""Temp/Vel Mode: Decreasing/Constant"""
1944  IF Itv=2 THEN PRINT USING "16X,""Temp/Vel Mode: Increasing/Constant"""
1948  INPUT "WANT TO RUN WILSON PLOT? (1=Y,0=N)",Iwil
1952  IF Ihm=1 AND Iwil=0 THEN
1956  IF Itt=0 THEN Ci=.032
1960  IF Itt=1 OR Itt=3 THEN Ci=.059
1964  IF Itt=2 OR Itt=4 THEN Ci=.062
1968  BEEP
1972  INPUT "ENTER CI (DEF: WH=.032,HF=.059,TB=.062)",Ci
1976  PRINT USING "16X,""Sieder-Tate """
1980  PRINT USING "16X,""  Constant   = "",Z.4D";Ci
1984  END IF
1988  END IF
1992  IF Ihm=1 AND Im=1 AND Iwil=1 THEN
1996  IF Itt=0 THEN Ci=.032
2000  IF Itt=1 OR Itt=3 THEN Ci=.059
2004  IF Itt=2 OR Itt=4 THEN Ci=.062
2008  ASSIGN @File2 TO *
2012  CALL Wilson(Cf,Ci)
2016  ASSIGN @File2 TO D2_file$
2020  ENTER @File2;Nrun,Dold$,Ldtc1,Ldtc2,Itt
2024  END IF
2028  Nsub=0
2032  IF Idp=4 THEN Ihm=1
2036  IF Ihm=1 THEN Nsub=8
2040  Ntc=6
2041  IF Ihm=0 THEN Ntc=12
2044  J=1
2048  Sx=0
2052  Sy=0
2056  Sxs=0
2060  Sxy=0
2064 Repeat: !
2068  IF Im=0 THEN
2072  Dtld=2.22
2076  Ido=2
2080  ON KEY 0,15 RECOVER 2064
2084  PRINTER IS 1
2088  PRINT USING "4X,""SELECT OPTION"""
2092  PRINT USING "6X,""0=TAKE DATA"""
2096  IF Ihm=0 THEN PRINT USING "6X,""1=SET HEAT FLUX"""
2100  IF Ihm=1 THEN PRINT USING "6X,""1=SET WATER FLOW RATE"""
2104  PRINT USING "6X,""2=SET Tsat"""
2108  PRINT USING "4X,""NOTE: KEY 0 = ESCAPE"""
2112  BEEP
2116  INPUT Ido
2120  IF Ido>2 THEN Ido=2
2124  IF Ido=0 THEN 2724
2128!
2132! LOOP TO SET HEAT FLUX OR FLOWMETER SETTING
2136  IF Ido=1 THEN
2140  IF Ihm=0 THEN
```

```
2148  BEEP
2152  INPUT "ENTER DESIRED Qdp",Dqdp
2156  PRINT USING "4X,""DESIRED Qdp  ACTUAL Qdp"""
2160  Err=1000
2164  FOR I=1 TO 2
2165  Sum(I)=0
2166  Vt(I)=0
2168  NEXT I
2169  OUTPUT 709;"RST"
2176  FOR Ji=1 TO 5
2180  OUTPUT 709;"CONFMEAS DCV,512-513,USE 600"
2181  FOR I=1 TO 2
2182  ENTER 709;Vt(I)
2184  Sum(I)=Sum(I)+Vt(I)
2185  NEXT I
2188  NEXT Ji
2189  FOR I=1 TO 2
2192  IF I=1 THEN Volt=Sum(I)/5
2196  IF I=2 THEN Amp=Sum(I)/5
2200  NEXT I
2201  Amp=ABS(Amp*1.9182)
2202  Volt=ABS(Volt*25)
2204  Aqdp=Volt*Amp/(PI*D2*L)
2208  IF ABS(Aqdp-Dqdp)>Err THEN
2212  IF Aqdp>Dqdp THEN
2216  BEEP 4000,.2
2220  BEEP 4000,.2
2224  BEEP 4000,.2
2228  ELSE
2232  BEEP 250,.2
2236  BEEP 250,.2
2240  BEEP 250,.2
2244  END IF
2248  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
2252  WAIT 2
2256  GOTO 2164
2260  ELSE
2264  BEEP
2268  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
2272  Err=500
2276  WAIT 2
2280  GOTO 2164
2284  END IF
2288  ELSE
2292  BEEP
2296  INPUT "ENTER FLOWMETER SETTING",Fms
2300  GOTO 2088
2304  END IF
2308  END IF
2312!
2316! LOOP TO SET Tsat
2320  IF Ido=2 THEN
2324  IF Ikdt=1 THEN 2344
2328  BEEP
2332  INPUT "ENTER DESIRED Tsat",Dtld
2336! PRINT USING "4X,"" DTsat  ATsat   Rate    Tv     Rate"""
2340  Ikdt=1
2344  Old1=0
2348  Old2=0
2352  Nn=1
```

```
2356  Nrs=Nn MOD 15
2360  Nn=Nn+1
2364  IF Nrs=1 THEN
2365  IF Ihm=0 THEN PRINT USING "4X,""   Tsat      Tld1      Tld2      Tv        Tsum
p"""
2368  IF Ihm=1 THEN PRINT USING "4X,""   Tsat    Tld1    Tld2    Tv    Tsump  Tinle
t   Tpile  Tout"""
2372  END IF
2373  FOR I=1 TO 6
2374  Sum(I)=0
2375  NEXT I
2376  OUTPUT 709;"RST"
2377  FOR Ji=1 TO 20
2379  IF Ihm=0 THEN OUTPUT 709;"CONFMEAS TEMPT,508-511,USE 600"
2380  IF Ihm=1 THEN OUTPUT 709;"CONFMEAS TEMPT,300-305,USE 600"
2384  FOR I=1 TO 6
2388  IF Ihm=0 AND I>4 THEN 2401
2392  ENTER 709;Eliq(I)
2396  Sum(I)=Sum(I)+Eliq(I)
2400  NEXT I
2401  NEXT Ji
2402  FOR I=1 TO 6
2403  IF Ihm=0 AND I>4 THEN 2496
2416  Eliq(I)=Sum(I)/20
2424  IF I=1 THEN Tld1=Eliq(I)
2428  IF I=2 THEN Tld2=Eliq(I)
2432  IF I=3 THEN Tv=Eliq(I)
2436  IF I=4 THEN Tsump=Eliq(I)
2440  IF I=5 THEN Tinlet=Eliq(I)
2444  IF I=6 THEN Tout=Eliq(I)
2448  NEXT I
2452  IF Ihm=1 THEN
2456  Sum1=0
2460  OUTPUT 709;"RST"
2468  FOR Kk=1 TO 20
2469  OUTPUT 709;"CONFMEAS TEMPT,320,USE 600"
2472  ENTER 709;E1
2476  Sum1=Sum1+E1
2480  NEXT Kk
2484  Emf(7)=ABS(Sum1/20)
2488  Tpile=Emf(7)/3.96E-4
2492  END IF
2496  Atld=(Tld1+Tld2)*.5
2500  IF ABS(Atld-Dtld)>.2 THEN
2504  IF Atld>Dtld THEN
2508  BEEP 4000,.2
2512  BEEP 4000,.2
2516  BEEP 4000,.2
2520  ELSE
2524  BEEP 250,.2
2528  BEEP 250,.2
2532  BEEP 250,.2
2536  END IF
2540  Err1=Atld-Old1
2544  Old1=Atld
2548  Err2=Tv-Old2
2552  Old2=Tv
2553  IF Tld1>100. THEN 2572
2556  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2560  IF Ihm=1 AND Idp=0 THEN PRINT USING "4X,7(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Ts
```

```
ump,Tinlet,Tpile
2564  IF Ihm=1 AND Idp=4 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,2X)";Dtld,Tl
d1,Tld2,Tv,Tsump,Tinlet,Tpile,Tout
2568  WAIT 2
2572  GOTO 2356
2576  ELSE
2580  IF ABS(Atld-Dtld)>.1 THEN
2584  IF Atld>Dtld THEN
2588  BEEP 3000,.2
2592  BEEP 3000,.2
2596  ELSE
2600  BEEP 800,.2
2604  BEEP 800,.2
2608  END IF
2612  Err1=Atld-Old1
2616  Old1=Atld
2620  Err2=Tv-Old2
2624  Old2=Tv
2628  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2632  IF Ihm=1 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,1X)";Dtld,Tld1,Tld2,Tv
,Tsump,Tinlet,Tpile,Tout
2636  WAIT 2
2640  GOTO 2356
2644  ELSE
2648  BEEP
2652  Err1=Atld-Old1
2656  Old1=Atld
2660  Err2=Tv-Old2
2664  Old2=Tv
2668  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2672  IF Ihm=1 THEN PRINT USING "4X,8(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump,Tinlet
,Tpile,Tout
2676  WAIT 2
2680  GOTO 2356
2684  END IF
2688  END IF
2692  END IF
2696! ERROR TRAP FOR Ido OUT OF BOUNDS
2700  IF Ido>2 THEN
2704  BEEP
2708  GOTO 2088
2712  END IF
2716!
2720! TAKE DATA IF Im=0 LOOP
2724  IF Ikol=1 THEN 2737
2728  BEEP
2732  INPUT "ENTER BULK OIL %",Bop
2736  Ikol=1
2737  FOR I=1 TO Ntc
2738  E(I)=0
2739  Sum(I)=0
2740  NEXT I
2741  OUTPUT 709;"RST"
2742  FOR Ji=1 TO 20
2744  IF Ihm=0 THEN OUTPUT 709;"CONFMEAS TEMPT,500-511,USE 600"
2745  IF Ihm=1 THEN OUTPUT 709;"CONFMEAS TEMPT,300-305,USE 600"
2748  IF Ihm=0 THEN Ntc=12
2752  FOR I=1 TO Ntc
2756  ENTER 709;E(I)
2760  Sum(I)=Sum(I)+E(I)
```

```
2776 IF I=(9-Nsub) THEN Et1(Ji-1)=E(I)
2777 IF I=(10-Nsub) THEN Et2(Ji-1)=E(I)
2778 NEXT I
2780 NEXT Ji
2784 Kdl=0
2785 FOR I=1 TO Ntc
2788 IF I=(9-Nsub) OR I=(10-Nsub) THEN
2792 Eave=Sum(I)/20
2797 Sum(I)=0
2798 END IF
2800 IF I=(9-Nsub) THEN
2801 FOR Jk=0 TO 19
2804 IF ABS(Et1(Jk)-Eave)<.1 THEN
2808 Sum(I)=Sum(I)+Et1(Jk)
2812 ELSE
2816 Kdl=Kdl+1
2817 END IF
2819 NEXT Jk
2820 END IF
2822 IF I=(10-Nsub) THEN
2823 FOR Jk=0 TO 19
2825 IF ABS(Et2(Jk)-Eave)<.1 THEN
2826 Sum(I)=Sum(I)+Et2(Jk)
2828 ELSE
2829 Kdl=Kdl+1
2830 END IF
2832 NEXT Jk
2833 END IF
2836 IF I=(9-Nsub) OR I=(10-Nsub) THEN PRINT USING "4X,""Kdl = "",DD";Kdl
2837 IF Kdl>10 THEN
2838 BEEP
2840 BEEP
2844 PRINT USING "4X,""Too much scattering in data - repeat data set"""
2848 GOTO 2084
2852 END IF
2860 Emf(I)=Sum(I)/(20-Kdl)
2864 NEXT I
2868 IF Ihm=1 THEN
2872 Sum(1)=0
2876 OUTPUT 709;"CONFMEAS TEMPT,320,USE 600"
2884 FOR Kk=1 TO 20
2888 ENTER 709;E(Kk)
2892 Sum(1)=Sum(1)+E(Kk)
2896 NEXT Kk
2900 Emf(7)=ABS(Sum(1))/20
2904 END IF
2908 IF Ihm=0 THEN
2909 FOR I=1 TO 2
2910 Sum(I)=0
2911 NEXT I
2912 OUTPUT 709;"RST"
2913 FOR Ji=1 TO 5
2915 OUTPUT 709;"CONFMEAS DCV,512-513,USE 600"
2916 FOR I=1 TO 2
2920 ENTER 709;E(I)
2936 Sum(I)=Sum(I)+E(I)
2937 NEXT I
2940 NEXT Ji
2941 FOR I=1 TO 2
2944 IF I=1 THEN Vr=Sum(I)/5
```

```
2948 IF I=2 THEN Ir=Sum(I)*1.9182/5
2952 NEXT I
2956 END IF
2960 ELSE
2964 IF Ihm=0 THEN ENTER @File2;Bop,Told,Emf(*),Vr,Ir
2968 IF Ihm=1 THEN ENTER @File2;Bop,Told,Emf(*),Fms
2972 END IF
2976!
2980! CONVERT emf'S TO TEMP,VOLT,CURRENT
2984 Twa=0
2988 FOR I=1 TO Ntc
2992 IF Idtc>0 THEN
2996 IF I=Ldtc1 OR I=Ldtc2 THEN
3000 T(I)=0
3004 GOTO 3044
3008 END IF
3012 END IF
3016 IF Itt<4 AND Ihm=0 THEN
3020 IF I>4 AND I<9 THEN
3024 T(I)=0
3028 GOTO 3044
3032 END IF
3036 END IF
3040 T(I)=Emf(I)
3044 NEXT I
3048 IF Itt<4 THEN
3052 FOR I=1 TO 4
3056 IF I=Ldtc1 OR I=Ldtc2 THEN
3060 Twa=Twa
3064 ELSE
3068 Twa=Twa+T(I)
3072 END IF
3076 NEXT I
3080 Twa=Twa/(4-Idtc)
3084 ELSE
3088 IF Ihm=1 THEN 3128
3092 FOR I=1 TO 8
3096 IF I=Ldtc1 OR I=Ldtc2 THEN
3100 Twa=Twa
3104 ELSE
3108 Twa=Twa+T(I)
3112 END IF
3116 NEXT I
3120 Tw=Twa/(8-Idtc)
3124 END IF
3128 Tld=T(9-Nsub)
3132 Tld2=T(10-Nsub)
3136 Tlda=(Tld+Tld2)*.5
3140 Tv=T(11-Nsub)
3158 Tsump=T(12-Nsub)
3160 IF Ihm=0 THEN 3176
3168 Tinlet=T(13-Nsub)
3172 Tout=T(14-Nsub)
3176 IF Ihm=0 THEN
3180 Amp=ABS(Ir)
3184 Volt=ABS(Vr)*25
3188 Q=Volt*Amp
3192 END IF
3196 IF Itt=0 AND Ihm=0 THEN
3200 Kcu=FNKcu(Tw)
```

```
3204  ELSE
3208  Kcu=Kcua(Itt)
3212  END IF
3216!
3220! FOURIER CONDUCTION EQUATION WITH CONTACT RESISTANCE NEGLECTED
3224  IF Ihm=0 THEN Tw=Tw-Q*LOG(D2/D1)/(2*PI*Kcu*L)
3228  IF Ilqv=0 THEN Tsat=Tlda
3232  IF Ilqv=1 THEN Tsat=(Tlda+Tv)*.5
3236  IF Ilqv=2 THEN Tsat=Tv
3244  IF Ihm=1 THEN
3248  Tavg=Tinlet
3252  Grad=37.9853+.104388*Tavg
3256  Tdrop=ABS(Emf(7))*1.E+6/(10*Grad)
3260  Tavgc=Tinlet-Tdrop*.5
3264  IF ABS(Tavg-Tavgc)>.01 THEN
3268  Tavg=(Tavg+Tavgc)*.5
3272  GOTO 3252
3276  END IF
3280!
3284! COMPUTE WATER PROPERTIES
3288  IF Ihm=1 THEN
3292  Kw=FNKw(Tavg)
3296  Muwa=FNMuw(Tavg)
3300  Cpw=FNCpw(Tavg)
3304  Prw=FNPrw(Tavg)
3308  Rhow=FNRhow(Tavg)
3312  Twi=Tavg
3316!
3320! Compute MDOT
3324  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
3328! Mdot=Mdot*(1.0365-Tinlet*(1.96644E-3-Tinlet*5.252E-6))/1.0037
3332  Kdt=0
3336  Q=Mdot*Cpw*Tdrop
3340  Lmtd=Tdrop/LOG((Tinlet-Tsat)/(Tinlet-Tdrop-Tsat))
3344  Uo=Q/(PI*Do*L*Lmtd)
3348  Rw=Do*LOG(Do/Di)/(2.*Kcu)
3352  Tw=Tsat+Fr*Lmtd
3356  Vw=Mdot/(Rhow*PI*Di^2/4)
3360  Rew=Rhow*Vw*Di/Muwa
3364  Hi=Ci*Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
3368  Twic=Tavg-Q/(PI*Do*L*Hi)
3372  IF ABS(Twi-Twic)>.01 THEN
3376  Twi=(Twi+Twic)*.5
3380  GOTO 3364
3384  END IF
3388  Twi=(Twi+Twic)*.5
3392  Ho=1/(1/Uo-Do/(Di*Hi)-Rw)
3396  END IF
3397  END IF
3399  IF Ihm=1 THEN
3400  Thetab=Q/(Ho*PI*Do*L)
3404  Tw=Tsat+Thetab
3405  ELSE
3408  Thetab=Tw-Tsat
3411  END IF
3413  IF Thetab<0 THEN
3416  BEEP
3420  INPUT "TWALL<TSAT (0=CONTINUE, 1=END)",Iev
3424  IF Iev=0 THEN GOTO 2068
```

```
3428  IF Iev=1 THEN 3832
3432  END IF
3440!
3444! COMPUTE VARIOUS PROPERTIES
3452  Tfilm=(Tw+Tsat)*.5
3456  Rho=FNRho(Tfilm)
3460  Mu=FNMu(Tfilm)
3464  K=FNK(Tfilm)
3468  Cp=FNCp(Tfilm)
3472  Beta=FNBeta(Tfilm)
3476  Hfg=FNHfg(Tsat)
3480  Ni=Mu/Rho
3484  Alpha=K/(Rho*Cp)
3488  Pr=Ni/Alpha
3492  Psat=FNPsat(Tsat)
3496!
3500! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
3504! FOR UNENHANCED END(S)
3508  Hbar=190
3512  Fe=(Hbar*P/(Kcu*A))^.5*Lu
3516  Tanh=FNTanh(Fe)
3520  Theta=Thetab*Tanh/Fe
3524  Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
3528  Yy=(1+(.559/Pr)^(9/16))^(8/27)
3532  Hbarc=K/Do*(.6+.387*Xx/Yy)^2
3536  IF ABS((Hbar-Hbarc)/Hbarc)>.001 THEN
3540  Hbar=(Hbar+Hbarc)*.5
3544  GOTO 3512
3548  END IF
3552!
3556! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S)
3560  Ql=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
3564  Qc=Q-2*Ql
3568  As=PI*D2*L
3572!
3576! COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT
3580  Qdp=Qc/As
3584  Htube=Qdp/Thetab
3588  Csf=(Cp*Thetab/Hfg)/(Qdp/(Mu*Hfg)*(.014/(9.81*Rho)^.5)^(1/3.)*Pr^1.7)
3592!
3596! RECORD TIME OF DATA TAKING
3600  IF Im=0 THEN
3604  OUTPUT 709;"TIMEDATE"
3608  ENTER 709;Told
3612  END IF
3616!
3620! OUTPUT DATA TO PRINTER
3624  PRINTER IS 701
3628  IF Iov=0 THEN
3632  PRINT
3636  PRINT USING "10X,""Data Set Number = "",DDD,2X,""Bulk Oil % = "",DD.D,5X,1
4A";J,Bop,TIME$(Told)
3640  IF Ihm=0 THEN
3644  PRINT USING "10X,""TC No:     1       2       3       4       5       6       7
   8"""
3648  PRINT USING "10X,""Temp :"",8(1X,MDD.DD)";T(1),T(2),T(3),T(4),T(5),T(6),T(
7),T(8)
3652  PRINT USING "10X,"" Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump"""
3656  PRINT USING "10X,2(MDD.DD,1X),1X,MDD.DD,1X,2(1X,MDD.DD),2X,MDD.D";Tw,Tld,T
ld2,Tv,Psat,Tsump
```

```
3660  PRINT USING "10X,"" Thetab  Htube      Qdp"""
3664  PRINT USING "10X,MDD.3D,1X,MZ.3DE,1X,MZ.3DE";Thetab,Htube,Qdp
3668  ELSE
3672  PRINT USING "10X,"" Fms     Vw    Tsat   Tinl Tdrop Thetab     q          Uo
      Ho"""
3676  PRINT USING "10X,4(2D.DD,1X),Z.3D,1X,DD.DD,1X,3(MZ.3DE,1X)";Fms,Vw,Tsat,Ti
nlet,Tdrop,Thetab,Qdp,Uo,Ho
3680  END IF
3684  END IF
3688  IF Iov=1 THEN
3692  IF J=1 THEN
3696  PRINT
3700  IF Ihm=0 THEN
3704  PRINT USING "10X,"" RUN No  Oil%  Tsat    Htube      Qdp        Thetab"""
3708  ELSE
3712  PRINT USING "10X,""  FMS    OIL%  TSAT    HTUBE      QDP        THETAB"""
3716  END IF
3720  END IF
3724  IF Ihm=0 THEN
3728  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";J,Bop,Tsat,Htube,Qdp,The
tab
3732  ELSE
3736  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";Fms,Bop,Tsat,Htube,Qdp,T
hetab
3740  END IF
3744  END IF
3748  IF Im=0 THEN
3752  BEEP
3756  INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Ok
3760  END IF
3764  IF Ok=1 OR Im=1 THEN J=J+1
3768  IF Ok=1 AND Im=0 THEN
3772  IF Ihm=0 THEN OUTPUT @File1;Bop,Told,Emf(*),Vr,Ir
3776  IF Ihm=1 THEN OUTPUT @File1;Bop,Told,Emf(*),Fms
3780  END IF
3784  IF Iuf=1 THEN OUTPUT @Ufile;Vw,Uo
3788  IF Ire=1 THEN OUTPUT @Refile;Fms,Rew
3792  IF (Im=1 OR Ok=1) AND Iplot=1 THEN OUTPUT @Plot;Qdp,Thetab
3796  IF Im=0 THEN
3800  BEEP
3804  INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
3808  Nrun=J
3812  IF Go_on=0 THEN 3832
3816  IF Go_on<>0 THEN Repeat
3820  ELSE
3824  IF J<Nrun+1 THEN Repeat
3828  END IF
3832  IF Im=0 THEN
3836  BEEP
3840  PRINT USING "10X,""NOTE: "",ZZ,"" data runs were stored in file "",10A";J-
1,D2_file$
3844  ASSIGN @File1 TO *
3848  OUTPUT @File2;Nrun-1
3852  ASSIGN @File1 TO D1_file$
3856  ENTER @File1;Dt,Ldtc1,Ldtc2,Itt
3860  OUTPUT @File2;Dt,Ldtc1,Ldtc2,Itt
3864  FOR I=1 TO Nrun-1
3868  IF Ihm=0 THEN
3872  ENTER @File1;Bop,Told,Emf(*),Vr,Ir
3876  OUTPUT @File2;Bop,Told,Emf(*),Vr,Ir
```

```
3880  ELSE
3884  ENTER @File1;Bop,Told,Emf(*),Fms
3888  OUTPUT @File2;Bop,Told,Emf(*),Fms
3892  END IF
3896  NEXT I
3900  ASSIGN @File1 TO *
3904  PURGE "DUMMY"
3908  END IF
3912  BEEP
3916  PRINT
3920  IF Iplot=1 THEN PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in
 plot data file "",10A";J-1,P_file$
3924  ASSIGN @File2 TO *
3928  ASSIGN @Plot TO *
3932  IF Iuf=1 THEN ASSIGN @Ufile TO *
3936  IF Ire=1 THEN ASSIGN @Refile TO *
3940  CALL Stats
3944  BEEP
3948  INPUT "LIKE TO PLOT DATA (1=Y,0=N)?",Ok
3952  IF Ok=1 THEN CALL Plot
3956  SUBEND
3960!
3964! CURVE FITS OF PROPERTY FUNCTIONS
3968  DEF FNKcu(T)
3972! OFHC COPPER 250 TO 300 K
3976  Tk=T+273.15      !C TO K
3980  K=434-.112*Tk
3984  RETURN K
3988  FNEND
3992  DEF FNMu(T)
3996! 170 TO 360 K CURVE FIT OF VISCOUSITY
4000  Tk=T+273.15      !C TO K
4004  Mu=EXP(-4.4636+(1011.47/Tk))*1.0E-3
4008  RETURN Mu
4012  FNEND
4016  DEF FNCp(T)
4020! 180 TO 400 K CURVE FIT OF Cp
4024  Tk=T+273.15      !C TO K
4028  Cp=.40188+1.65007E-3*Tk+1.51494E-6*Tk^2-6.67853E-10*Tk^3
4032  Cp=Cp*1000
4036  RETURN Cp
4040  FNEND
4044  DEF FNRho(T)
4048  Tk=T+273.15      !C TO K
4052  X=1-(1.8*Tk/753.95)  !K TO R
4056  Ro=36.32+61.146414*X^(1/3)+16.418015*X+17.476838*X^.5+1.119828*X^2
4060  Ro=Ro/.062428
4064  RETURN Ro
4068  FNEND
4072  DEF FNPr(T)
4076  Pr=FNCp(T)*FNMu(T)/FNK(T)
4080  RETURN Pr
4084  FNEND
4088  DEF FNK(T)
4092! T<360 K WITH T IN C
4096  K=.071-.000261*T
4100  RETURN K
4104  FNEND
4108  DEF FNTanh(X)
4112  P=EXP(X)
```

```
4116  Q=1/P
4120  Tanh=(P-Q)/(P+Q)
4124  RETURN Tanh
4128  FNEND
4138!
4184  DEF FNBeta(T)
4188  Rop=FNRho(T+.1)
4192  Rom=FNRho(T-.1)
4196  Beta=-2/(Rop+Rom)*(Rop-Rom)/.2
4200  RETURN Beta
4204  FNEND
4208  DEF FNHfg(T)
4212  Hfg=1.3741344E+5-T*(3.3094361E+2+T*1.2165143)
4216  RETURN Hfg
4220  FNEND
4224  DEF FNPsat(Tc)
4228! 0 TO 80 deg F CURVE FIT OF Psat
4232  Tf=1.8*Tc+32
4236  Pa=5.945525+Tf*(.15352082+Tf*(1.4840963E-3+Tf*9.6150671E-6))
4240  Pg=Pa-14.7
4244  IF Pg>0 THEN       ! +=PSIG,-=in Hg
4248  Psat=Pg
4252  ELSE
4256  Psat=Pg*29.92/14.7
4260  END IF
4264  RETURN Psat
4268  FNEND
4272  DEF FNHsmooth(X,Bop,Isat)
4276  DIM A(5),B(5),C(5),D(5)
4280  DATA .20526,.25322,.319048,.55322,.79909,1.00258
4284  DATA .74515,.72992,.73189,.71225,.68472,.64197
4288  DATA .41092,.17726,.25142,.54806,.81916,1.0845
4292  DATA .71403,.72913,.72565,.696691,.665867,.61889
4296  READ A(*),B(*),C(*),D(*)
4300  IF Bop<6 THEN I=Bop
4304  IF Bop=6 THEN I=4
4308  IF Bop=10 THEN I=5
4312  IF Isat=1 THEN
4316  Hs=EXP(A(I)+B(I)*LOG(X))
4320  ELSE
4324  Hs=EXP(C(I)+D(I)*LOG(X))
4328  END IF
4332  RETURN Hs
4336  FNEND
4340  DEF FNPoly(X)
4344  COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4348  X1=X
4352  Poly=B(0)
4356  FOR I=1 TO Nop
4360  IF Ilog=1 THEN X1=LOG(X)
4364  Poly=Poly+B(I)*X1^I
4368  NEXT I
4372  IF Ilog=1 THEN Poly=EXP(Poly)
4376  RETURN Poly
4380  FNEND
4384  SUB Poly
4388  DIM R(10),S(10),Sy(12),Sx(12),Xx(100),Yy(100)
4392  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4396  COM /Xxyy/ Xp(25),Yp(25)
4400  FOR I=0 TO 4
```

```
4404  B(I)=0
4408  NEXT I
4412  BEEP
4416  INPUT "SELECT (0=FILE,1=KEYBOARD,2=PROGRAM)",Im
4420  Im=Im+1
4424  BEEP
4428  INPUT "ENTER NUMBER OF X-Y PAIRS",Np
4432  IF Im=1 THEN
4436  BEEP
4440  INPUT "ENTER DATA FILE NAME",D_file$
4444  BEEP
4448  INPUT "LIKE TO EXCLUDE DATA PAIRS (1=Y,0=N)?",Ied
4452  IF Ied=1 THEN
4456  BEEP
4460  INPUT "ENTER NUMBER OF PAIRS TO BE EXCLUDED",Ipex
4464  END IF
4468  ASSIGN @File TO D_file$
4472  ELSE
4476  BEEP
4480  INPUT "WANT TO CREATE A DATA FILE (1=Y,0=N)?",Yes
4484  IF Yes=1 THEN
4488  BEEP
4492  INPUT "GIVE A NAME FOR DATA FILE",D_file$
4496  CREATE BDAT D_file$,5
4500  ASSIGN @File TO D_file$
4504  END IF
4508  END IF
4512  BEEP
4516  INPUT "ENTER THE ORDER OF POLYNOMIAL",N
4520  FOR I=0 TO N*2
4524  Sy(I)=0
4528  Sx(I)=0
4532  NEXT I
4536  IF Ied=1 AND Im=1 THEN
4540  FOR I=1 TO Ipex
4544  ENTER @File;X,Y
4548  NEXT I
4552  END IF
4556  FOR I=1 TO Np
4560  IF Im=1 THEN
4564  IF Opo=2 THEN ENTER @File;X,Y
4568  IF Opo<2 THEN ENTER @File;Y,X
4572  IF Opo=1 THEN Y=Y/X
4576  IF Ilog=1 THEN
4580  IF Opo=2 THEN Xt=X/Y
4584  X=LOG(X)
4588  IF Opo=2 THEN Y=LOG(Xt)
4592  IF Opo<2 THEN Y=LOG(Y)
4596  END IF
4600  END IF
4604  IF Im=2 THEN
4608  BEEP
4612  INPUT "ENTER NEXT X-Y PAIR",X,Y
4616  IF Yes=1 THEN OUTPUT @File;X,Y
4620  END IF
4624  IF Im<3 THEN
4628  Xx(I)=X
4632  Yy(I)=Y
4636  ELSE
4640  X=Xp(I-1)
```

```
4644  Y=Yp(I-1)
4648  END IF
4652  R(0)=Y
4656  Sy(0)=Sy(0)+Y
4660  S(1)=X
4664  Sx(1)=Sx(1)+X
4668  FOR J=1 TO N
4672  R(J)=R(J-1)*X
4676  Sy(J)=Sy(J)+R(J)
4680  NEXT J
4684  FOR J=2 TO N*2
4688  S(J)=S(J-1)*X
4692  Sx(J)=Sx(J)+S(J)
4696  NEXT J
4700  NEXT I
4704  IF Yes=1 AND Im=2 THEN
4708  BEEP
4712  PRINT USING "12X,DD,"" X-Y pairs were stored in file "",10A";Np,D_file$
4716  END IF
4720  Sx(0)=Np
4724  FOR I=0 TO N
4728  C(I)=Sy(I)
4732  FOR J=0 TO N
4736  A(I,J)=Sx(I+J)
4740  NEXT J
4744  NEXT I
4748  FOR I=0 TO N-1
4752  CALL Divide(I)
4756  CALL Subtract(I+1)
4760  NEXT I
4764  B(N)=C(N)/A(N,N)
4768  FOR I=0 TO N-1
4772  B(N-1-I)=C(N-1-I)
4776  FOR J=0 TO I
4780  B(N-1-I)=B(N-1-I)-A(N-1-I,N-J)*B(N-J)
4784  NEXT J
4788  B(N-1-I)=B(N-1-I)/A(N-1-I,N-1-I)
4792  NEXT I
4796 !PRINTER IS 701
4800 !PRINT B(*)
4804 !PRINTER IS 705
4808  IF Iprnt=0 THEN
4812  PRINT USING "12X,""EXPONENT    COEFFICIENT"""
4816  FOR I=0 TO N
4820  PRINT USING "15X,DD,5X,MD.7DE";I,B(I)
4824  NEXT I
4828  PRINT " "
4832  PRINT USING "12X,""DATA POINT      X              Y       Y(CALCULATED) DISCR
EPANCY"""
4836  FOR I=1 TO Np
4840  Yc=B(0)
4844  FOR J=1 TO N
4848  Yc=Yc+B(J)*Xx(I)^J
4852  NEXT J
4856  D=Yy(I)-Yc
4860  PRINT USING "15X,3D,4X,4(MD.5DE,1X)";I,Xx(I),Yy(I),Yc,D
4864  NEXT I
4868  END IF
4872  ASSIGN @File TO *
4876  SUBEND
```

```
4880  SUB Divide(M)
4884  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4888  FOR I=M TO N
4892  Ao=A(I,M)
4896  FOR J=M TO N
4900  A(I,J)=A(I,J)/Ao
4904  NEXT J
4908  C(I)=C(I)/Ao
4912  NEXT I
4916  SUBEND
4920  SUB Subtract(K)
4924  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4928  FOR I=K TO N
4932  FOR J=K-1 TO N
4936  A(I,J)=A(K-1,J)-A(I,J)
4940  NEXT J
4944  C(I)=C(K-1)-C(I)
4948  NEXT I
4952  SUBEND
4956  SUB Plin
4960  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4964  COM /Xxyy/ Xx(25),Yy(25)
4968  PRINTER IS 705
4972  BEEP
4976  INPUT "WANT TO PLOT Uo vs Vw? (1=Y,0=N)",Iuo
4980  IF Iuo=0 THEN
4984  BEEP
4988  INPUT "SELECT (0=h/h0% same tube,1=h(HF)/h(sm)",Irt
4992  BEEP
4996  INPUT "SELECT h/h RATIO (1=FILE,0=COMPUTED)",Ihrat
5000  IF Ihrat=0 THEN
5004  BEEP
5008  INPUT "WHICH Tsat (1=6.7,0=-2.2)",Isat
5012  END IF
5016  Xmin=0
5020  Xmax=10
5024  Xstep=2
5028  IF Irt=0 THEN
5032  Ymin=0
5036  Ymax=1.4
5040  Ystep=.2
5044  ELSE
5048  Ymin=0
5052  Ymax=15
5056  Ystep=5
5060  END IF
5064  ELSE
5068  Opo=2
5072  Ymin=0
5076  Ymax=12
5080  Ystep=3
5084  Xmin=0
5088  Xmax=4
5092  Xstep=1
5096  END IF
5100  IF Ihrat=1 THEN
5104  Ymin=0
5108  Ymax=18
5112  Ystep=3
5116  Xmin=0
```

```
5120  Xmax=9
5124  Xstep=2
5128  END IF
5132  BEEP
5136  PRINT "IN;SP1;IP 2300,2200,8300,6800;"
5140  PRINT "SC 0,100,0,100;TL 2,0;"
5144  Sfx=100/(Xmax-Xmin)
5148  Sfy=100/(Ymax-Ymin)
5152  PRINT "PU 0,0 PD"
5156  FOR Xa=Xmin TO Xmax STEP Xstep
5160  X=(Xa-Xmin)*Sfx
5164  PRINT "PA";X,",0; XT;"
5168  NEXT Xa
5172  PRINT "PA 100,0;PU;"
5176  PRINT "PU PA 0,0 PD"
5180  FOR Ya=Ymin TO Ymax STEP Ystep
5184  Y=(Ya-Ymin)*Sfy
5188  PRINT "PA 0,";Y,"YT"
5192  NEXT Ya
5196  PRINT "PA 0,100 TL 0 2"
5200  FOR Xa=Xmin TO Xmax STEP Xstep
5204  X=(Xa-Xmin)*Sfx
5208  PRINT "PA";X,",100; XT"
5212  NEXT Xa
5216  PRINT "PA 100,100 PU PA 100,0 PD"
5220  FOR Ya=Ymin TO Ymax STEP Ystep
5224  Y=(Ya-Ymin)*Sfy
5228  PRINT "PD PA 100,",Y,"YT"
5232  NEXT Ya
5236  PRINT "PA 100,100 PU"
5240  PRINT "PA 0,-2 SR 1.5,2"
5244  FOR Xa=Xmin TO Xmax STEP Xstep
5248  X=(Xa-Xmin)*Sfx
5252  PRINT "PA";X,",0;"
5256  IF Iuo=0 THEN PRINT "CP -2,-1;LB";Xa;""
5260  IF Iuo=1 THEN PRINT "CP -1.5,-1;LB";Xa;""
5264  NEXT Xa
5268  PRINT "PU PA 0,0"
5272  FOR Ya=Ymin TO Ymax STEP Ystep
5276  IF ABS(Ya)<1.E-5 THEN Ya=0
5280  Y=(Ya-Ymin)*Sfy
5284  PRINT "PA 0,";Y,""
5288  IF Iuo=0 THEN PRINT "CP -4,-.25;LB";Ya;""
5292  IF Iuo=1 THEN PRINT "CP -3,-.25;LB";Ya;""
5296  NEXT Ya
5300  Xlabel$="Oil Percent"
5304  IF Iuo=0 THEN
5308  IF Irt=0 THEN
5312  Ylabel$="h/h0%"
5316  ELSE
5320  Ylabel$="h/hsmooth"
5324  END IF
5328  PRINT "SR 1.5,2;PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
5332  PRINT "PA -11,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
5336  PRINT "CP 0,0"
5340  ELSE
5344  PRINT "SP0;SP2"
5348  PRINT "SR 1.2,2.4;PU PA -8,35;DI 0,1;LBU;PR 1,0.5;LBo;PR -1,0.5;LB (kW/m
"
5352  PRINT "PR -1,0.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
```

```
5356  PRINT "PA 42,-10;DI 1,0;LBV;PR .4,-1;LBw;PR 1,.5;LB(m/s)"
5360  PRINT "SP0;SP1"
5364  END IF
5368  Ipn=0
5372  BEEP
5376  INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Okp
5380  Icn=0
5384  IF Okp=1 THEN
5388  BEEP
5392  INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
5396! IF Iuo=0 THEN
5400  BEEP
5404  INPUT "SELECT (0=LINEAR, 1=LOG(X,Y)",Ilog
5408! END IF
5412  ASSIGN @File TO D_file$
5416  BEEP
5420  INPUT "ENTER THE BEGINNING RUN NUMBER",Md
5424  BEEP
5428  INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
5432  IF Iuo=0 AND Ihrat=0 THEN
5436  BEEP
5440  INPUT "ENTER DESIRED HEAT FLUX",Q
5444  END IF
5448  BEEP
5452  PRINTER IS 1
5456  PRINT USING "4X,""Select a symbol:"""
5460  PRINT USING "4X,""1  Star    2  Plus sign"""
5464  PRINT USING "4X,""3  Circle 4  Square"""
5468  PRINT USING "4X,""5  Rombus"""
5472  PRINT USING "4X,""6  Right-side-up triangle"""
5476  PRINT USING "4X,""7  Up-side-down triangle"""
5480  INPUT Sym
5484  PRINTER IS 705
5488  PRINT "PU DI"
5492  IF Sym=1 THEN PRINT "SM*"
5496  IF Sym=2 THEN PRINT "SM+"
5500  IF Sym=3 THEN PRINT "SMo"
5504  Nn=4
5508  IF Ilog=1 THEN Nn=1
5512  IF Md>1 THEN
5516  FOR I=1 TO (Md-1)
5520  ENTER @File;Xa,Ya
5524  NEXT I
5528  END IF
5532  IF Ihrat=0 THEN
5536  Q1=Q
5540  IF Ilog=1 THEN Q=LOG(Q)
5544  END IF
5548  FOR I=1 TO Npairs
5552  IF Iuo=0 AND Ihrat=0 THEN
5556  ENTER @File;Xa,B(*)
5560  Ya=B(0)
5564  FOR K=1 TO Nn
5568  Ya=Ya+B(K)*Q^K
5572  NEXT K
5576  END IF
5580  IF Iuo=1 OR Ihrat=1 THEN
5584  ENTER @File;Xa,Ya
5588  IF Iuo=1 THEN Ya=Ya/1000
5592  END IF
```

```
5596  IF Iuo=0 AND Ihrat=0 THEN
5600  IF Ilog=1 THEN Ya=EXP(Ya)
5604  IF Ilog=0 THEN Ya=Q1/Ya
5608  IF Irt=0 THEN
5612  IF Xa=0 THEN
5616  Yo=Ya
5620  Ya=1
5624  ELSE
5628  Ya=Ya/Yo
5632  END IF
5636  ELSE
5640  Hsm=FNHsmooth(Q,Xa,Isat)
5644  Ya=Ya/Hsm
5648  END IF
5652  END IF
5656  Xx(I-1)=Xa
5660  Yy(I-1)=Ya
5664  X=(Xa-Xmin)*Sfx
5668  Y=(Ya-Ymin)*Sfy
5672  IF Sym>3 THEN PRINT "SM"
5676  IF Sym<4 THEN PRINT "SR 1.4,2.4"
5680  PRINT "PA",X,Y,""
5684  IF Sym>3 THEN PRINT "SR 1.2,1.6"
5688  IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0,;"
5692  IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
5696  IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
5700  IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
5704  NEXT I
5708  BEEP
5712  ASSIGN @File TO *
5716  END IF
5720  PRINT "PU SM"
5724  BEEP
5728  INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Okp
5732  IF Okp=1 THEN
5736  BEEP
5740  PRINTER IS 1
5744  PRINT USING "4X,""Select line type:"""
5748  PRINT USING "6X,""0      Solid line"""
5752  PRINT USING "6X,""1      Dashed"""
5756  PRINT USING "6X,""2,,,5 Longer line - dash"""
5760  INPUT Ipn
5764  PRINTER IS 705
5768  BEEP
5772  INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
5776  Iprnt=1
5780  CALL Poly
5784  IF Iuo=1 THEN
5788  BEEP
5792  INPUT "DESIRE TO SET X Lower and Upper Limit (1=Y,0=N)?",Ixlim
5796  IF Ixlim=0 THEN
5800  Xll=0
5804  Xul=7
5808  END IF
5812  IF Ixlim=1 THEN
5816  BEEP
5820  INPUT "ENTER X Lower Limit",Xll
5824  BEEP
5828  INPUT "ENTER X Upper Limit",Xul
5832  END IF
```

```
5836 END IF
5840 FOR Xa=Xll TO Xul STEP Xstep/25
5844 Icn=Icn+1
5848 Ya=FNPoly(Xa)
5852 IF Iuo=1 THEN Ya=Ya/1000
5856 Y=(Ya-Ymin)*Sfy
5860 X=(Xa-Xmin)*Sfx
5864 IF Y<0 THEN Y=0
5868 IF Y>100 THEN GOTO 5908
5872 Pu=0
5876 IF Ipn=1 THEN Idf=Icn MOD 2
5880 IF Ipn=2 THEN Idf=Icn MOD 4
5884 IF Ipn=3 THEN Idf=Icn MOD 8
5888 IF Ipn=4 THEN Idf=Icn MOD 16
5892 IF Ipn=5 THEN Idf=Icn MOD 32
5896 IF Idf=1 THEN Pu=1
5900 IF Pu=0 THEN PRINT "PA",X,Y,"PD"
5904 IF Pu=1 THEN PRINT "PA",X,Y,"PU"
5908 NEXT Xa
5912 PRINT "PU"
5916 GOTO 5372
5920 END IF
5924 BEEP
5928 INPUT "WANT TO QUIT (1=Y,0=N)?",Iquit
5932 IF Iquit=1 THEN 5940
5936 GOTO 5372
5940 PRINT "PU SP0"
5944 SUBEND
5948 SUB Stats
5952 PRINTER IS 701
5956 J=0
5960 K=0
5964 BEEP
5968 IF Iplot=1 THEN ASSIGN @File TO P_file$
5972 BEEP
5976 INPUT "LAST RUN No?(0=QUIT)",Nn
5980 IF Nn=0 THEN 6124
5984 Nn=Nn-J
5988 Sx=0
5992 Sy=0
5996 Sz=0
6000 Sxs=0
6004 Sys=0
6008 Szs=0
6012 FOR I=1 TO Nn
6016 J=J+1
6020 ENTER @File;Q,T
6024 H=Q/T
6028 Sx=Sx+Q
6032 Sxs=Sxs+Q^2
6036 Sy=Sy+T
6040 Sys=Sys+T^2
6044 Sz=Sz+H
6048 Szs=Szs+H^2
6052 NEXT I
6056 Qave=Sx/Nn
6060 Tave=Sy/Nn
6064 Have=Sz/Nn
6068 Sdevq=SQR(ABS((Nn*Sxs-Sx^2)/(Nn*(Nn-1))))
6072 Sdevt=SQR(ABS((Nn*Sys-Sy^2)/(Nn*(Nn-1))))
```

```
6076  Sdevh=SQR(ABS((Nn*Szs-Sz^2)/(Nn*(Nn-1))))
6080  Sh=100*Sdevh/Have
6084  Sq=100*Sdevq/Qave
6088  St=100*Sdevt/Tave
6092  IF K=1 THEN 6116
6096  PRINT
6100  PRINT USING "11X,""DATA FILE:"",14A";File$
6104  PRINT
6108  PRINT USING "11X,""RUN Htube     SdevH   Qdp         SdevQ   Thetab SdevT""
"
6112  K=1
6116  PRINT USING "11X,DD,2(2X,D.3DE,1X,3D.2D),2X,DD.3D,1X,3D.2D";J,Have,Sh,Qave
,Sq,Tave,St
6120  GOTO 5972
6124  ASSIGN @File1 TO *
6128  PRINTER IS 1
6132  SUBEND
6136  SUB Coef
6140  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
6144  BEEP
6148  INPUT "GIVE A NAME FOR CROSS-PLOT FILE",Cpf$
6152  CREATE BDAT Cpf$,2
6156  ASSIGN @File TO Cpf$
6160  BEEP
6164  INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
6168  BEEP
6172  INPUT "ENTER OIL PERCENT (-1=STOP)",Bop
6176  IF Bop<0 THEN 6192
6180  CALL Poly
6184  OUTPUT @File;Bop,B(*)
6188  GOTO 6168
6192  ASSIGN @File TO *
6196  SUBEND
6200  SUB Wilson(Cf,Ci)
6204  COM /Wil/ D2,Di,Do,L,Lu,Kcu
6208  DIM Emf(12)
62121 WLISON PLOT SUBROUTINE DETERMINE CF AND CI
6216  BEEP
6220  INPUT "ENTER DATA FILE NAME",File$
6224  BEEP
6228  PRINTER IS 1
6232  PRINT USING "4X,""Select option:"""
6236  PRINT USING "4X,""  0 Vary Cf and  Ci"""
6240  PRINT USING "4X,""  1 Fix  Cf Vary Ci"""
6244  PRINT USING "4X,""  2 Vary Cf Fix  Ci"""
6248  INPUT "ENTER OPTION",Icfix
6252  PRINTER IS 701
6256  IF Icfix=0 THEN 6272
6260  IF Icfix>0 THEN BEEP
6264  IF Icfix=1 THEN INPUT "ENTER Cf",Csf
6268  IF Icfix=2 THEN INPUT "ENTER CI",Ci
6272  PRINTER IS 1
6276  INPUT "Want To Vary Coeff?(1=Y,0=N)",Iccoef
6280  IF Iccoef=1 THEN INPUT "ENTER COEFF",R
6284  PRINTER IS 701
6288  IF Icfix=0 OR Icfix=2 THEN Cfa=.004
6292  IF Icfix=1 THEN Cfa=Csf
6296  Cia=Ci
6300  Xn=.8
6304  Fr=.3
```

```
6308  Jj=0
6312  Rr=3.
6316  IF Iccoef=1 THEN Rr=R
6320  PRINTER IS 1
6324  PRINT Do,Di,Kcu
6328  ASSIGN @File TO File$
6332  ENTER @File;Nrun,Dt,Ldtc1,Ldtc2,Itt
6336  Rw=Do*LOG(Do/Di)/(2*Kcu)
6340  Sx=0
6344  Sy=0
6348  Sxy=0
6352  Sx2=0
6356  Sy2=0
6360  FOR I=1 TO Nrun
6364  ENTER @File;Bop,TIME$(Told),Emf(*),Fms
6368! CONVERT EMF'S TO TEMPERATURE
6372  FOR J=1 TO 5
6376  T(J)=FNTvsv(Emf(J))
6380  NEXT J
6384  Tsat=(T(1)+T(2))*.5
6388  Tavg=T(5)
6392  Grad=37.9853+.104388*Tavg
6396  Tdrop=Emf(7)*1.E+6/(10.*Grad)
6400  Tavgc=T(5)-Tdrop*.5
6404  IF ABS(Tavg-Tavgc)>.01 THEN
6408  Tavg=(Tavg+Tavgc)*.5
6412  GOTO 6392
6416  END IF
6420!
6424! Compute properties of water
6428  Kw=FNKw(Tavg)
6432  Muwa=FNMuw(Tavg)
6436  Cpw=FNCpw(Tavg)
6440  Prw=FNPrw(Tavg)
6444  Rhow=FNRhow(Tavg)
6448!
6452! Compute properties of Freon-114
6456  Lmtd=Tdrop/LOG((T(5)-Tsat)/(T(5)-Tdrop-Tsat))
6460  IF Jj=0 THEN
6464  Tw=Tsat+Fr*Lmtd
6468  Thetab=Tw-Tsat
6472  Jj=1
6476  END IF
6480  Tf=(Tw+Tsat)*.5
6484  Rho=FNRho(Tf)
6488  Mu=FNMu(Tf)
6492  K=FNK(Tf)
6496  Cp=FNCp(Tf)
6500  Beta=FNBeta(Tf)
6504  Hfg=FNHfg(Tsat)
6508  Ni=Mu/Rho
6512  Alpha=K/(Rho*Cp)
6516  Pr=Ni/Alpha
6520!
6524! Analysis
6528! COMPUTE MDOT
6532  A=PI*(Do^2-Di^2)/4
6536  P=PI*Do
6540  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
```

```
6544  Q=Mdot*Cpw*Tdrop
6548! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
6552! FOR UNENHANCED END(S)
6556  Hbar=190
6560  Fe=(Hbar*P/(Kcu*A))^.5*Lu
6564  Tanh=FNTanh(Fe)
6568  Theta=Thetab*Tanh/Fe
6572  Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
6576  Yy=(1+(.559/Pr)^(9/16))^(8/27)
6580  Hbarc=K/Do*(.6+.387*Xx/Yy)^2
6584  IF ABS((Hbar-Hbarc)/Hbar)>.001 THEN
6588  Hbar=(Hbar+Hbarc)*.5
6592  GOTO 6560
6596  END IF
6600!
6604! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED ENDS
6608  Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
6612  Qc=Q-2*Q1
6616  As=PI*D2*L
6620! COMPUTE ACTUAL HEAT FLUX
6624  Qdp=Qc/As
6628  IF Icfix=0 OR Icfix>1 THEN Csf=1/Cf^(1./Rr)
6632  Thetab=Csf/Cp*Hfg*(Qdp/(Mu*Hfg)*(.014/(9.81*Rho))^.5)^(1/Rr)*Pr^1.7
6636  Ho=Qdp/Thetab
6640  Omega=Ho/Cf
6644  Uo=Q/(PI*Do*L*Lmtd)
6648  Vw=Mdot/(Rhow*PI*Di^2/4)
6652  Rew=Rhow*Vw*Di/Muwa
6656  Twi=Tw+Q*Rw/(PI*Do*L)
6660  Gama=Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
6664! PRINTER IS 1
6668  Yw=(1./Uo-Rw)*Omega
6672  Xw=Omega*Do/(Gama*Di)
6676  Sx=Sx+Xw
6680  Sy=Sy+Yw
6684  Sxy=Sxy+Yw*Xw
6688  Sx2=Sx2+Xw*Xw
6692  Sy2=Sy2+Yw*Yw
6696  NEXT I
6700  ASSIGN @File TO *
6704  M=(Sx*Sy-Nrun*Sxy)/(Sx*Sx-Nrun*Sx2)
6708  C=(Sy-Sx*M)/Nrun
6712  IF Icfix=0 OR Icfix=3 OR Icfix=4 THEN
6716  Cic=1/M
6720  Cfc=1/C
6724  END IF
6728  IF Icfix=1 THEN
6732  Cic=1/M
6736  Cfc=Cf
6740  END IF
6744  IF Icfix=2 THEN
6748  Cic=Ci
6752  Cfc=1/C
6756  END IF
6760  IF ABS((Ci-Cic)/Cic)>.001 OR ABS((Cf-Cfc)/Cfc)>.001 THEN
6764  Ci=(Ci+Cic)*.5
6768  Cf=(Cf+Cfc)*.5
6772  PRINTER IS 1
6776  PRINT USING "2X,"" Csf = "",MZ.3DE,2X,"" Ci = "",MZ.3DE";Csf,Ci
6780  PRINTER IS 701
```

```
6784  GOTO 6328
6788  END IF
6792  PRINT
6796  PRINTER IS 701
6800  PRINT USING "23X,""  Cf            Ci"""
6804  PRINT USING "8X,""ASSUMED        "",MZ.3DE,3X,MZ.3DE";Cfa,Cia
6808  PRINT USING "8X,""CALCULATED     "",MZ.3DE,3X,MZ.3DE";Csf,Ci
6812  PRINT
6816  Sum2=Sy2-2*M*Sxy-2*C*Sy+M^2*Sx2+2*M*C*Sx+Nrun*C^2
6820  PRINT USING "10X,""Sum of Squares = "",Z.3DE";Sum2
6824  PRINT USING "10X,""Coefficient = "",D.DDD";Rr
6828  SUBEND
6832  DEF FNMuu(T)
6836  A=247.8/(T+133.15)
6840  Mu=2.4E-5*10^A
6844  RETURN Mu
6848  FNEND
6852  DEF FNCpu(T)
6856  Cpu=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
6860  RETURN Cpu*1000
6864  FNEND
6868  DEF FNRhou(T)
6872  Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
6876  RETURN Ro
6880  FNEND
6884  DEF FNPru(T)
6888  Pru=FNCpu(T)*FNMuu(T)/FNKu(T)
6892  RETURN Pru
6896  FNEND
6900  DEF FNKu(T)
6904  X=(T+273.15)/273.15
6908  Ku=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
6912  RETURN Ku
6916  FNEND
6920  SUB Plot
6924  COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
6928  DIM Bs(3)
6932  INTEGER Ii
6936  PRINTER IS 1
6940  Idv=0
6944  BEEP
6948  INPUT "LIKE DEFAULT VALUES FOR PLOT (1=Y,0=N)?",Idv
6952  Opo=0
6956  BEEP
6960  PRINT USING "4X,""Select Option:"""
6964  PRINT USING "6X,""0  q versus delta-T"""
6968  PRINT USING "6X,""1  h versus delta-T"""
6972  PRINT USING "6X,""2  h versus q"""
6976  INPUT Opo
6980  BEEP
6984  INPUT "SELECT UNITS (0=SI,1=ENGLISH)",Iun
6988  PRINTER IS 705
6992  IF Idv<>1 THEN
6996  BEEP
7000  INPUT "ENTER NUMBER OF CYCLES FOR X-AXIS",Cx
7004  BEEP
7008  INPUT "ENTER NUMBER OF CYCLES FOR Y-AXIS",Cy
7012  BEEP
7016  INPUT "ENTER MIN X-VALUE (MULTIPLE OF 10)",Xmin
7020  BEEP
```

```
7024  INPUT "ENTER MIN Y-VALUE (MULTIPLE OF 10)",Ymin
7028  ELSE
7032  IF Opo=0 THEN
7036  Cy=3
7040  Cx=3
7044  Xmin=.1
7048  Ymin=100
7052  END IF
7056  IF Opo=1 THEN
7060  Cy=2
7064  Cx=2
7068  Xmin=.1
7072  Ymin=100
7076  END IF
7080  IF Opo=2 THEN
7081  IF Iun=0 THEN
7084  Cy=3
7088  Cx=2
7092  Xmin=1000
7096  Ymin=100
7097  ELSE
7098  Cy=3
7099  Cx=3
7100  Xmin=100
7101  Ymin=10
7102  END IF
7104  END IF
7105  END IF
7108  BEEP
7112  PRINT "IN;SP1;IP 2300,2200,8300,6800;"
7116  PRINT "SC 0,100,0,100;TL 2,0;"
7120  Sfx=100/Cx
7124  Sfy=100/Cy
7128  BEEP
7132  INPUT "WANT TO BY-PASS CAGE? (1=Y,0=N)",Ibyp
7136  IF Ibyp=1 THEN 7632
7140  PRINT "PU 0,0 PD"
7144  Nn=9
7148  FOR I=1 TO Cx+1
7152  Xat=Xmin*10^(I-1)
7156  IF I=Cx+1 THEN Nn=1
7160  FOR J=1 TO Nn
7164  IF J=1 THEN PRINT "TL 2 0"
7168  IF J=2 THEN PRINT "TL 1 0"
7172  Xa=Xat*J
7176  X=LGT(Xa/Xmin)*Sfx
7180  PRINT "PA";X,",0; XT;"
7184  NEXT J
7188  NEXT I
7192  PRINT "PA 100,0;PU;"
7196  PRINT "PU PA 0,0 PD"
7200  Nn=9
7204  FOR I=1 TO Cy+1
7208  Yat=Ymin*10^(I-1)
7212  IF I=Cy+1 THEN Nn=1
7216  FOR J=1 TO Nn
7220  IF J=1 THEN PRINT "TL 2 0"
7224  IF J=2 THEN PRINT "TL 1 0"
7228  Ya=Yat*J
7232  Y=LGT(Ya/Ymin)*Sfy
```

```
7236 PRINT "PA 0,";Y,"YT"
7240 NEXT J
7244 NEXT I
7248 PRINT "PA 0,100 TL 0 2"
7252 Nn=9
7256 FOR I=1 TO Cx+1
7260 Xat=Xmin*10^(I-1)
7264 IF I=Cx+1 THEN Nn=1
7268 FOR J=1 TO Nn
7272 IF J=1 THEN PRINT "TL 0 2"
7276 IF J>1 THEN PRINT "TL 0 1"
7280 Xa=Xat*J
7284 X=LGT(Xa/Xmin)*Sfx
7288 PRINT "PA";X,",100; XT"
7292 NEXT J
7296 NEXT I
7300 PRINT "PA 100,100 PU PA 100,0 PD"
7304 Nn=9
7308 FOR I=1 TO Cy+1
7312 Yat=Ymin*10^(I-1)
7316 IF I=Cy+1 THEN Nn=1
7320 FOR J=1 TO Nn
7324 IF J=1 THEN PRINT "TL 0 2"
7328 IF J>1 THEN PRINT "TL 0 1"
7332 Ya=Yat*J
7336 Y=LGT(Ya/Ymin)*Sfy
7340 PRINT "PD PA 100,",Y,"YT"
7344 NEXT J
7348 NEXT I
7352 PRINT "PA 100,100 PU"
7356 PRINT "PA 0,-2 SR 1.5,2"
7360 Ii=LGT(Xmin)
7364 FOR I=1 TO Cx+1
7368 Xa=Xmin*10^(I-1)
7372 X=LGT(Xa/Xmin)*Sfx
7376 PRINT "PA";X,",0;"
7380 IF Ii>=0 THEN PRINT "CP -2,-2;LB10;PR -2,2;LB";Ii;""
7384 IF Ii<0 THEN PRINT "CP -2,-2;LB10;PR 0,2;LB";Ii;""
7388 Ii=Ii+1
7392 NEXT I
7396 PRINT "PU PA 0,0"
7400 Ii=LGT(Ymin)
7404 Y10=10
7408 FOR I=1 TO Cy+1
7412 Ya=Ymin*10^(I-1)
7416 Y=LGT(Ya/Ymin)*Sfy
7420 PRINT "PA 0,";Y,""
7424 PRINT "CP -4,-.25;LB10;PR -2,2;LB";Ii;""
7428 Ii=Ii+1
7432 NEXT I
7436 BEEP
7440 INPUT "WANT USE DEFAULT LABELS (1=Y,0=N)?",Idl
7444 IF Idl<>1 THEN
7448 BEEP
7452 INPUT "ENTER X-LABEL",Xlabel$
7456 BEEP
7460 INPUT "ENTER Y-LABEL",Ylabel$
7464 END IF
7468 IF Opo<2 THEN
7472 PRINT "SR 1,2;PU PA 40,-14;"
```

```
7476  PRINT "LB(T;PR -1.6,3 PD PR 1.2,0 PU;PR .5,-4;LBwo;PR .5,1;"
7480  PRINT "LB-T;PR .5,-1;LBsat;PR .5,1;"
7484  IF Iun=0 THEN
7488  PRINT "LB) (K)"
7492  ELSE
7496  PRINT "LB) (F)"
7500  END IF
7504  END IF
7508  IF Opo=2 THEN
7512  IF Iun=0 THEN
7516  PRINT "SR 1.5,2;PU PA 40,-14;LBq (W/m;SR 1,1.5;PR 0.5,1;LB2;SR 1.5,2;PR
0.5,-1;LB)"
7520  ELSE
7524  PRINT "SR 1.5,2;PU PA 34,-14;LBq (Btu/hr;PR .5,.5;LB.;PR .5,-.5;"
7528  PRINT "LBft;PR .5,1;SR 1,1.5;LB2;SR 1.5,2;PR .5,-1;LB);"
7532  END IF
7536  END IF
7540  IF Opo=0 THEN
7544  IF Iun=0 THEN
7548  PRINT "SR 1.5,2;PU PA -12,40;DI 0,1;LBq (W/m;PR -1,0.5;SR 1,1.5;LB2;SR 1
.5,2;PR 1,.5;LB)"
7552  ELSE
7556  PRINT "SR 1.5,2;PU PA -12,32;DI 0,1;LBq (Btu/hr;PR -.5,.5;LB.;PR .5,.5;"
7560  PRINT "LBft;SR 1,1.5;PR -1,.5;LB2;PR 1,.5;SR 1.5,2;LB)"
7564  END IF
7568  END IF
7572  IF Opo>0 THEN
7576  IF Iun=0 THEN
7580! PRINT "SR 1.5,2;PU PA -12,38;DI 0,1;LBh (W/m;PR -1,.5;SR 1,1.5;LB2;SR 1.
5,2;PR .5,.5;"
7584  PRINT "SR 1.2,2.4;PU PA -12,37;DI 0,1;LBh;PR 1,0.5;LBo;PR -1,0.5;LB (W/m
"
7588  PRINT "PR -1,.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
7592  ELSE
7596  PRINT "SR 1.5,2;PU PA -12,28;DI 0,1;LBh (Btu/hr;PR -.5,.5;LB.;PR .5,.5;"
7600  PRINT "LBft;PR -1,.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,.5;LBF)"
7604  END IF
7608  END IF
7612  IF Idl=0 THEN
7616  PRINT "SR 1.5,2;PU PA 50,-16 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
7620  PRINT "PA -14,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
7624  PRINT "CP 0,0 DI"
7628  END IF
7632  Ipn=0
7636  Xll=1.E+6
7640  Xul=-1.E+6
7644  Icn=0
7648  Ifn=0
7652  Ijoin=1
7656  BEEP
7660  INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Ok
7664  IF Ok=1 THEN
7668  BEEP
7672  INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
7676  ASSIGN @File TO D_file$
7680  BEEP
7684  BEEP
7688  INPUT "ENTER THE BEGINNING RUN NUMBER",Md
7692  BEEP
7696  INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
```

```
7700! BEEP
7704! INPUT "CONNECT DATA WITH LINE (1=Y,0=N)?",Icl
7708 BEEP
7712 PRINTER IS 1
7716 PRINT USING "4X,""Select a symbol:"""
7720 PRINT USING "6X,""1  Star      2  Plus sign"""
7724 PRINT USING "6X,""3  Circle    4  Square"""
7728 PRINT USING "6X,""5  Rombus"""
7732 PRINT USING "6X,""6  Right-side-up triangle"""
7736 PRINT USING "6X,""7  Up-side-down triangle"""
7740 INPUT Sym
7744 PRINTER IS 705
7748 PRINT "PU DI"
7752 IF Sym=1 THEN PRINT "SM*"
7756 IF Sym=2 THEN PRINT "SM+"
7760 IF Sym=3 THEN PRINT "SMo"
7764 IF Md>1 THEN
7768 FOR I=1 TO (Md-1)
7772 ENTER @File;Ya,Xa
7776 NEXT I
7780 END IF
7784 FOR I=1 TO Npairs
7788 ENTER @File;Ya,Xa
7792 IF I=1 THEN Q1=Ya
7796 IF I=Npairs THEN Q2=Ya
7800 IF Opo=1 THEN Ya=Ya/Xa
7804 IF Opo=2 THEN
7808 Q=Ya
7812 Ya=Ya/Xa
7816 Xa=Q
7820 END IF
7824 IF Xa<Xll THEN Xll=Xa
7828 IF Xa>Xul THEN Xul=Xa
7832 IF Iun=1 THEN
7836 IF Opo<2 THEN Xa=Xa*1.8
7840 IF Opo>0 THEN Ya=Ya*.1761
7844 IF Opo=0 THEN Ya=Ya*.317
7848 IF Opo=2 THEN Xa=Xa*.317
7852 END IF
7856 X=LGT(Xa/Xmin)*Sfx
7860 Y=LGT(Ya/Ymin)*Sfy
7864 Kj=0
7868 CALL Symb(X,Y,Sym,Icl,Kj)
7872 GOTO 7924
7876 IF Sym>3 THEN PRINT "SM"
7880 IF Sym<4 THEN PRINT "SR 1.4,2.4"
7884 IF Icl=0 THEN
7888 PRINT "PA",X,Y,""
7892 ELSE
7896 PRINT "PA",X,Y,"PD"
7900 END IF
7904 IF Sym>3 THEN PRINT "SR 1.2,1.6"
7908 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
7912 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
7916 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
7920 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
7924 NEXT I
7928 PRINT "PU"
7932 BEEP
7936 INPUT "WANT TO LABEL? (1=Y,0=N)",Ilab
```

```
7940 IF Ilab=1 THEN
7944 PRINT "SP0;SP2"
7948 BEEP
7952 IF Klab=0 THEN
7956 Xlab=5
7960 Ylab=85
7964 INPUT "ENTER INITIAL X,Y LOCATIONS",Xlab,Ylab
7968 Xtt=Xlab-5
7972 Ytt=Ylab+8
7976 PRINT "SR 1,1.5"
7980 PRINT "SM;PA",Xtt,Ytt,"LB       %   Heat   File"
7984 Ytt=Ytt-3
7988 PRINT "PA",Xtt,Ytt,"LB      Oil   Flux   Name"
7992 IF Sym=1 THEN PRINT "SM*"
7996 IF Sym=2 THEN PRINT "SM+"
8000 IF Sym=3 THEN PRINT "SMo"
8004 Klab=1
8008 END IF
8012 Kj=1
8016 CALL Symb(Xlab,Ylab,Sym,Icl,Kj)
8020 PRINT "SR 1,1.5;SM"
8024 IF Sym<4 THEN PRINT "PR 2,0"
8028 BEEP
8032 INPUT "ENTER BOP",Bop
8036 IF Bop<10 THEN PRINT "PR 2,0;LB";Bop;""
8040 IF Bop>9 THEN PRINT "PR .5,0;LB";Bop;""
8044 Ihf=0
8048 IF Q1>Q2 THEN Ihf=1
8052 IF Ihf=0 THEN PRINT "PR 4,0;LBInc"
8056 IF Ihf=1 THEN PRINT "PR 4,0;LBDec"
8060 PRINT "PR 2,0;LB";D_file$;""
8064 PRINT "SP0;SP1;SR 1.5,2"
8068 Ylab=Ylab-5
8072 END IF
8076 BEEP
8080 ASSIGN @File TO *
8084 Xll=Xll/1.2
8088 Xul=Xul*1.2
8092! GOTO 8040
8096 END IF
8100 PRINT "PU SM"
8104 BEEP
8108 INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Go_on
8112 IF Go_on=1 THEN
8116 BEEP
8120 PRINTER IS 1
8124 PRINT USING "4X,""Select line type:"""
8128 PRINT USING "6X,""0      Solid line"""
8132 PRINT USING "6X,""1      Dashed"""
8136 PRINT USING "6X,""2,,,5 Longer line - dash"""
8140 INPUT Ipn
8144 PRINTER IS 705
8148 BEEP
8152 INPUT "SELECT (0=LIN,1=LOG(X,Y))",Ilog
8156 Iprnt=1
8160 CALL Poly
8164 IF Ifn=0 THEN
8168 BEEP
8172 INPUT "ENTER NUMBER OF FILES TO JOIN?",Njoin
8176 END IF
```

```
8180  Ijoin=0
8184  IF Ifn<Njoin THEN Ijoin=1
8188  IF Ifn=0 OR Ijoin=1 THEN
8192  FOR Ij=0 TO 3
8196  Bs(Ij)=Bs(Ij)+B(Ij)
8200  NEXT Ij
8204  Ifn=Ifn+1
8208  END IF
8212  IF Njoin=Ifn THEN
8216  FOR Ij=0 TO 3
8220  B(Ij)=Bs(Ij)/Njoin
8224  Bs(Ij)=0
8228  NEXT Ij
8232  Ifn=0
8236  ELSE
8240  GOTO 7656
8244  END IF
8248  BEEP
8252  INPUT "ENTER Y LOWER AND UPPER LIMITS",Yll,Yul
8256  FOR Xx=0 TO Cx STEP Cx/200
8260  Xa=Xmin*10^Xx
8264  IF Xa<Xll OR Xa>Xul THEN 8372
8268  Icn=Icn+1
8272  Pu=0
8276  IF Ipn=1 THEN Idf=Icn MOD 2
8280  IF Ipn=2 THEN Idf=Icn MOD 4
8284  IF Ipn=3 THEN Idf=Icn MOD 8
8288  IF Ipn=4 THEN Idf=Icn MOD 16
8292  IF Ipn=5 THEN Idf=Icn MOD 28
8296  IF Idf=1 THEN Pu=1
8300  IF Opo=0 THEN Ya=FNPoly(Xa)
8304  IF Opo=2 AND Ilog=0 THEN Ya=Xa/FNPoly(Xa)
8308  IF Opo=2 AND Ilog=1 THEN Ya=FNPoly(Xa)
8312  IF Opo=1 THEN Ya=FNPoly(Xa)
8316  IF Ya<Ymin THEN 8372
8320  IF Ya<Yll OR Ya>Yul THEN 8372
8324  IF Iun=1 THEN
8328  IF Opo<2 THEN Xa=Xa*1.8
8332  IF Opo>0 THEN Ya=Ya*.1761
8336  IF Opo=0 THEN Ya=Ya*.317
8340  IF Opo=2 THEN Xa=Xa*.317
8344  END IF
8348  Y=LGT(Ya/Ymin)*Sfy
8352  X=LGT(Xa/Xmin)*Sfx
8356  IF Y<0 THEN Y=0
8360  IF Y>100 THEN GOTO 8372
8364  IF Pu=0 THEN PRINT "PA",X,Y,"PD"
8368  IF Pu=1 THEN PRINT "PA",X,Y,"PU"
8372  NEXT Xx
8376  PRINT "PU"
8380  GOTO 7656
8384  END IF
8388  BEEP
8392  INPUT "WANT TO PLOT REILLY'S DATA? (1=Y,0=N)",Irly
8396  IF Opo=0 OR Opo=1 THEN
8400  Xll=3
8404  Xul=20
8408  END IF
8412  IF Opo=2 THEN
8416  Xll=10000
```

```
8420 Xul=100000
8424 END IF
8428 IF Irly=1 THEN
8432 Yll=20
8436 Yul=70
8440 BEEP
8444 INPUT "ENTER LOWER AND UPPER Y-LIMITS FOR PLOTTING",Yll,Yul
8448 FOR Xx=0 TO Cx STEP Cx/200
8452 Xa=Xmin*10^Xx
8456 IF Xa<Xll OR Xa>Xul THEN 8508
8460 Xl=LOG(Xa)
8464 IF Opo=0 THEN Yl=-2.5402837E-1+Xl*(4.9720151-Xl*2.5134787E-1)
8468 IF Opo=1 THEN Yl=-2.5402837E-1+Xl*(3.9720151-Xl*2.5134787E-1)
8472 IF Opo=2 THEN Yl=-3.7073801E-1+Xl*(8.7259190E-1-Xl*6.8826842E-3)
8476 Ya=EXP(Yl)
8480 Y=LGT(Ya/Ymin)*Sfy
8484 X=LGT(Xa/Xmin)*Sfx
8488 Ipu=0
8492 IF Y<Yll THEN Ipu=1
8496 IF Y>Yul THEN GOTO 8508
8500 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
8504 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
8508 NEXT Xx
8512 PRINT "PU"
8516 END IF
8520 BEEP
8524 INPUT "WANT TO PLOT ROHSENOW CORRELATION? (1=Y,0=N)",Irohs
8528 IF Irohs=1 THEN
8532 Yll=15
8536 Yul=80
8540 BEEP
8544 INPUT "ENTER Tsat (Deg C)",Tsat
8548 Csf=.0040
8552 BEEP
8556 INPUT "ENTER Csf (DEF=0.004)",Csf
8560 Tf=Tsat+2
8564 FOR Xx=0 TO Cx STEP Cx/200
8568 Xa=Xmin*10^Xx
8572 IF Xa<Xll OR Xa>Xul THEN 8684
8576 Xl=LOG(Xa)
8580 IF Opo<2 THEN Tf=Tsat+Xa/2
8584 Rho=FNRho(Tf)
8588 K=FNK(Tf)
8592 Mu=FNMu(Tf)
8596 Cp=FNCp(Tf)
8600 Hfg=FNHfg(Tsat)
8604 Ni=Mu/Rho
8608 Pr=Cp*Mu/K
8612 Omega=Csf*Hfg/Cp*((.014/(9.81*Rho))^.5/(Mu*Hfg))^(1./3)*Pr^1.7
8616 IF Opo=0 THEN Ya=(Xa/Omega)^3
8620 IF Opo=1 THEN Ya=(Xa/Omega)^3/Xa
8624 IF Opo=2 THEN Ya=Xa^(2./3)/Omega
8628 IF Opo=2 THEN
8632 Tfc=Tsat+Xa/Ya*.5
8636 IF ABS(Tf-Tfc)>.01 THEN
8640 Tf=(Tf+Tfc)*.5
8644 GOTO 8584
8648 END IF
8652 END IF
8656 Y=LGT(Ya/Ymin)*Sfy
```

```
8660 X=LGT(Xa/Xmin)*Sfx
8664 Ipu=0
8668 IF Y<Yll THEN Ipu=1
8672 IF Y>Yul THEN 8684
8676 IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
8680 IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
8684 NEXT Xx
8688 PRINT "PU"
8692 END IF
8696 BEEP
8700 INPUT "WANT TO QUIT (1=Y,0=N)",Iqt
8704 IF Iqt=1 THEN 8712
8708 GOTO 7636
8712 PRINT "PU PA 0,0 SP0"
8716 SUBEND
8720 SUB Symb(X,Y,Sym,Icl,Kj)
8724 IF Sym>3 THEN PRINT "SM"
8728 IF Sym<4 THEN PRINT "SR 1.4,2.4"
8732 Yad=0
8736 IF Kj=1 THEN Yad=.8
8740 IF Icl=0 THEN
8744 PRINT "PA",X,Y+Yad,""
8748 ELSE
8752 PRINT "PA",X,Y+Yad,"PD"
8756 END IF
8760 IF Sym>3 THEN PRINT "SR 1.2,1.6"
8764 IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
8768 IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
8772 IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
8776 IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
8780 IF Kj=1 THEN PRINT "SM;PR 0,-.8"
8784 SUBEND
8788 SUB Purg
8792 BEEP
8796 INPUT "ENTER FILE NAME TO BE DELETED",File$
8800 PURGE File$
8804 GOTO 8792
8808 SUBEND
8812 SUB Tdcn
8816 COM /Cc/ C(7),Ical
8820 DIM Emf(1)
8824 DATA 0.10086091,25727.94369,-767345.8295,78025595.81
8828 DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
8832 READ C(*)
8836 BEEP
8840 INPUT "GIVE A NAME FOR FILE TO BE CREATED",File$
8844 BEEP
8848 INPUT "SELECT TUBE (0=WH,1=HF,2=WT)",Itt
8852 BEEP
8856 INPUT "SELECT THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
8860 IF Itt<2 THEN Di=.0127
8864 CREATE BDAT File$,4
8868 ASSIGN @File TO File$
8872 OUTPUT @File;Itt
8876 J=0
8880 BEEP
8884 OUTPUT 709;"TIMEDATE"
8888 ENTER 709;Dt
8900 PRINTER IS 1
8904 PRINT
```

```
8908  PRINT "           Month, date and time: ";DATE$(Dt),TIME$(Dt)
8912  PRINT
8916  PRINT USING "10X,"" Fms      Tin      Tev      Vw^2     Tdrop"""
8920  IF K=0 THEN
8924  PRINTER IS 701
8928  PRINT
8932  PRINT "           Month, date and time: ";DATE$(Dt),TIME$(Dt)
8936  IF Itt=0 THEN PRINT USING "10X,""Tube Type:           Wieland Smooth"""
8940  IF Itt=1 THEN PRINT USING "10X,""Tube Type:           High Flux"""
8944  IF Itt=2 THEN PRINT USING "10X,""Tube Type:           Turbo-B"""
8948  PRINT
8952  PRINT USING "10X,"" Fms      Tin      Tev      Vw^2      Tdrop"""
8956  PRINTER IS 1
8960  K=1
8964  END IF
8968  BEEP
8972  INPUT "ENTER FLOWMETER READING",Fms
8976  OUTPUT 709;"AR AF0 AL4 VR1"
8980  FOR L=0 TO 4
8984  OUTPUT 709;"AS SA"
8988  IF L>0 AND L<4 THEN 9020
8992  S=0
8996  FOR I=0 TO 9
9000  ENTER 709;E
9004  S=S+E
9008  NEXT I
9012  IF L=0 THEN Emf(0)=ABS(S/10)
9016  IF L=4 THEN Emf(1)=ABS(S/10)
9020  NEXT L
9024  OUTPUT 709;"AR AF20 AL20 VR1"
9028  OUTPUT 709;"AS SA"
9032  Etp=0
9036  FOR I=0 TO 9
9040  ENTER 709;Et
9044  Etp=Etp+Et
9048  NEXT I
9052  Etp=Etp/10
9056  Tin=FNTvsv(Emf(1))
9060  Tev=FNTvsv(Emf(0))
9064  Grad=37.9853+.104388*Tin
9068  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
9072  Vw=Mdot/(1000*PI*Di^2)*4
9076  Tdrop=Etp*1.E+6/(10*Grad)
9080  PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
9084  BEEP
9088  INPUT "WANT TO ACCEPT THIS DATA SET? (1=Y,0=N)",Ok
9092  J=J+1
9096  IF Ok=0 THEN
9100  J=J-1
9104  GOTO 8968
9108  ELSE
9112  OUTPUT @File;Fms,Emf(*),Etp
9116  PRINTER IS 701
9120  PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
9124  PRINTER IS 1
9128  BEEP
9132  INPUT "WILL THERE BE ANOTHER DATA SET? (1=Y,0=N)",Go_on
9136  IF Go_on=1 THEN 8968
9140  END IF
```

```
9144  ASSIGN @File TO *
9148  PRINTER IS 701
9152  PRINT
9156  PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";J,F
ile$
9160  PRINTER IS 1
9164  SUBEND
9168  SUB Uoprt
9172  PRINTER IS 1
9176  BEEP
9180  INPUT "Enter Uo File Name",File$
9184  BEEP
9188  INPUT "Number of Data Runs",Nrun
9192  INPUT "Do You Want a Plot File?(1=Y,0=N)",Iplot
9196  BEEP
9200  IF Iplot=1 THEN
9204  INPUT "Give Plot File Name",P_file$
9208  CREATE BDAT P_file$,4
9212  ASSIGN @Plot TO P_file$
9216  END IF
9220  PRINTER IS 701
9224  PRINT
9228  PRINT
9232  PRINT USING "10X,""   Water Vel          Uo"""
9236  ASSIGN @File TO File$
9240  IF Iplot=1 THEN ASSIGN @File1 TO P_file$
9244  FOR I=1 TO Nrun
9248  ENTER @File;Vw,Uo
9252  IF Iplot=1 THEN OUTPUT @File1;Vw,Uo
9256  PRINT USING "15X,D.DD,6X,MZ.3DE";Vw,Uo
9260  NEXT I
9264  ASSIGN @File TO *
9268  ASSIGN @File1 TO *
9272  PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";Nru
n,File$
9276  IF Iplot=1 THEN
9280  PRINT USING "10X,""NOTE: "",ZZ,"" X-Y Pairs are stored in file "",15A";Nru
n,P_file$
9284  END IF
9288  PRINTER IS 1
9292  SUBEND
9296  SUB Select
9300  COM /Idp/ Idp
9304  BEEP
9308  PRINTER IS 1
9312  PRINT USING "4X,""Select option:"""
9316  PRINT USING "6X,"" 0 Taking data or re-processing previous data"""
9320  PRINT USING "6X,"" 1 Plotting data on Log-Log """
9324  PRINT USING "6X,"" 2 Plotting data on Linear"""
9328  PRINT USING "6X,"" 3 Make cross-plot coefft file"""
9332  PRINT USING "6X,"" 4 Re-circulate water"""
9336  PRINT USING "6X,"" 5 Purge"""
9340  PRINT USING "6X,"" 6 T-Drop correction"""
9344  PRINT USING "6X,"" 7 Print Uo File"""
9345  PRINT USING "6X,"" 8 Modify X-Y file"""
9346  PRINT USING "6X,"" 9 Move"""
9347  PRINT USING "6X,""10 Comb/Fixup"""
9348  INPUT Idp
9352  IF Idp=0 THEN CALL Main
9356  IF Idp=1 THEN CALL Plot
```

```
9360  IF Idp=2 THEN CALL Plin
9364  IF Idp=3 THEN CALL Coef
9368  IF Idp=4 THEN CALL Main
9372  IF Idp=5 THEN CALL Purg
9376  IF Idp=6 THEN CALL Tdcn
9380  IF Idp=7 THEN CALL Uoprt
9381  IF Idp=8 THEN CALL Xymod
9382  IF Idp=9 THEN CALL Move
9383  IF Idp=10 THEN CALL Comb
9385  SUBEND
9394  SUB Xymod
9434  PRINTER IS 1
9444  BEEP
9454  INPUT "ENTER FILE NAME",File$
9464  ASSIGN @File1 TO File$
9474  BEEP
9484  INPUT "ENTER NUMBER OF X-Y PAIRS",Np
9494  BEEP
9504  INPUT "ENTER NEW FILE NAME",File2$
9514  CREATE BDAT File2$,5
9524  ASSIGN @File2 TO File2$
9534  BEEP
9544  INPUT "ENTER NUMBER OF X-Y PAIRS TO BE DELETED",Ndel
9554  IF Ndel=0 THEN 9594
9564  FOR I=1 TO Ndel
9574  BEEP
9584  INPUT "ENTER DATA SET NUMBER TO BE DELETED",Nd(I)
9594  NEXT I
9604  FOR J=1 TO Np
9614  ENTER @File1;X,Y
9624  FOR I=1 TO Ndel
9634  IF Nd(I)=J THEN 9674
9644  NEXT I
9654  OUTPUT @File2;X,Y
9664  PRINT J,X,Y
9674  NEXT J
9675  PRINTER IS 701
9684  ASSIGN @File1 TO *
9694  ASSIGN @File2 TO *
9704  SUBEND
9714  SUB Move
9718! FILE NAME: MOVE
9722!
9726  DIM Bop(66),A(66),B(66),C(66),D(66),E(66),F(66),G(66),H(66),J(66),K(66),L(
66),M(66)
9730  DIM Told(66),N(66),Vr(66),Ir(66)
9734  BEEP
9738  INPUT "OLD FILE TO MOVE",D2_file$
9742  ASSIGN @File2 TO D2_file$
9746  ENTER @File2;Nrun,Dt,Ldtc1,Ldtc2,Itt
9750  FOR I=1 TO Nrun
9754  ENTER @File2;Bop(I),Told(I)
9758  ENTER @File2;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),N
(I)
9762  ENTER @File2;Vr(I),Ir(I)
9766  NEXT I
9770  ASSIGN @File2 TO *
9774  BEEP
9778  INPUT "SHIFT DISK AND HIT CONTINUE",Ok
9782  BEEP
```

```
9786  INPUT "INPUT BDAT SIZE",Size
9790  CREATE BDAT D2_file$,Size
9794  ASSIGN @File1 TO D2_file$
9798  OUTPUT @File1;Nrun,Dt,Ldtc1,Ldtc2,Itt
9802  FOR I=1 TO Nrun
9806  OUTPUT @File1;Bop(I),Told(I)
9810  OUTPUT @File1;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),N(I)
9814  OUTPUT @File1;Vr(I),Ir(I)
9818  NEXT I
9822  ASSIGN @File1 TO *
9826! RENAME "TEST" TO D2_file$
9830  BEEP 2000,.2
9834  BEEP 4000,.2
9838  BEEP 4000,.2
9842  PRINT "DATA FILE MOVED"
9846  SUBEND
9874  SUB Comb
9878! FILE NAME: COMB
9882!
9886  DIM Emf(12)
9890  BEEP
9894  INPUT "OLD FILE TO FIXUP",D2_file$
9898  ASSIGN @File2 TO D2_file$
9902  D1_file$="TEST"
9906  CREATE BDAT D1_file$,20
9910  ASSIGN @File1 TO D1_file$
9914  ENTER @File2;Nrun,Dt,Ldtc1,Ldtc2,Itt
9915  Nrunm=20
9918  IF K=0 THEN OUTPUT @File1;Nrunm,Dt,Ldtc1,Ldtc2,Itt
9922  FOR I=1 TO Nrun
9926  ENTER @File2;Bop,Told,Emf(*),Vr,Ir
9930  OUTPUT @File1;Bop,Told,Emf(*),Vr,Ir
9934  NEXT I
9938  ASSIGN @File2 TO *
9942! RENAME "TEST" TO D2_file$
9946  BEEP 2000,.2
9950  BEEP 4000,.2
9954  BEEP 4000,.2
9958  BEEP
9962  INPUT "WANT TO ADD ANOTHER FILE (1=Y,0=N)?",Oka
9966  IF Oka=1 THEN
9970  K=1
9974  BEEP
9978  INPUT "GIVE NEW FILE NAME",Nfile$
9982  ASSIGN @File2 TO Nfile$
9986  GOTO 9914
9990  END IF
9994  ASSIGN @File2 TO *
9998  SUBEND
```

LIST OF REFERENCES

1. Incropera, F.P., and DeWitt, D.P., *Fundamentals of Heat Transfer,* 2nd Ed. John Wiley and Sons, Inc., New York, 1990, pp. 554 and 509.

2. Churchill, S.W., and Usagi, R., "A General Expression for the Correlation of Rates of Transfer and Other Phenomen," *A.J.Ch.E.* Jl 18, 1972, pp. 1121-1128.

3. Stephan, K., and Abdelsalam, M., "Heat-Transfer Correlations for Natural Convection Boiling," *Int. J. Heat Mass Transfer,* Vol. 23, 1980, pp. 73-87.

4. Yilmaz, K., and Westwater, J.W., "Effects of Commercial Enhanced Surfaces on the Boiling Heat Transfer Curve," *Advances in Heat Transfer-1981,* HTD-Vol. 18, ASME, 1981, pp. 73-92.

5. Carnavos, T.C., "An Experimental Study: Pool Boiling R-11 with Augmented Tubes," *Advances in Enhanced Heat Transfer,* ed. R.L. Webb *et al.*, ASME Publications, 1981, pp. 103-108.

6. Marto, P.J., and Lepere, V.J., "Pool Boiling Heat Transfer from Enhanced Surfaces to Dielectric Fluids," *Journal of Heat Transfer,* Vol. 104, May 1982, pp. 292-299.

7. Wanniarachchi, A.S., Marto, P.J. and Reilly, J.T., "The Effect of Oil Contamination on the Nucleate Pool-Boiling Performance of R-114 from a Porous-Coated Surface," *ASHRAE Transactions,* Vol. 92, pt. 2, 1986.

8. Wanniarachchi, A.S., Sawyer, L.M., and Marto, P.J., "Effect of Oil on Pool-Boiling Performance of R-114 from Enhanced Surfaces," *Proceedings 2nd ASME-JSME Thermal Engineering Joint Conference,* Honolulu, Hawaii, Vol.1, 1987, pp. 531-537.

9. Webb, R.L., "The Evolution of Enhanced Surface Geometries for Nucleate Boiling," *Heat Transfer Engineering,* Vol. 2, nos. 3-4, 1981, pp. 46-69.

10. McManus, S.M., Marto, P.J., and Wanniarachchi, A.S., "An Evaluation of Enhanced Heat Transfer Tubing for Use in R-114 Water Chillers," *Heat Transfer in Air Conditioning and Refrigeration Equipment,* HTD-Vol. 65, ASME, pp. 11-19.

11. Chaddock, J.B., "Influence of OIl on Refrigerant Evaporator Performance," *ASHRAE Transactions,* Vol. 82, pt. 1, pp. 474-486.

12. Sauer, H.J. Jr., Davidson, G.W., and Chongrungreong, S., "Nucleate Boiling of Refrigerant-Oil Mixtures from Finned Tubing," *Joint ASME/AIChE National Heat Transfer Conference,* Paper No. 80-HT-111, Orlando, 1980.

13. Murphy, T.J., "Pool Boiling of R-114/Oil Mixtures from Single Tubes and Tube Bundles," Master's Thesis, Naval Postgraduate School, Monterey, California.

14. Karasabun, M., "An Experimental Apparatus to Study Nucleate Pool Boiling of R-114 and Oil Mixtures," Master's Thesis, Naval Postgraduate School, Monterey, California.

15. Stephan, K., and Mitrovic, J., "Heat Transfer in Natural Convective Boiling of Refrigerants and Refrigerant-Oil Mixtures in Bundles of T-shaped Finned Tubes," *Advances in Enhanced Heat Transfer,* ed. R.L. Webb *et al.,* ASME Publications, 1981, pp. 131-146.

16. Marto, P.J., Wanniarachchi, A.S. and Pulido, R.J., "Augmenting the Nucleate Pool-Boiling Characteristics of GEWA-T Finned Tubes in R-113," *Advances in Enhanced Heat Transfer,* HTD-Vol. 18, ASME, pp. 67-73.

17. Kline, S.J., and McClintock, F.A., "Describing Uncertainties in Single-Sample Experiments," *Mechanical Engineering,* January 1953, p. 3.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 52 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Professor Paul J. Marto, Code ME/Mx Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943-5000	2
4.	Professor Stephen Memory, Code ME/Mr Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943-5000	1
5.	Department Chairman, Code ME Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943-5000	1
6.	Naval Engineering Curricular Officer, Code 34 Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93943-5000	1
7.	Mr. R. Helmick David Taylor Research Center Annnapolis, Maryland 21402-5067	1
8.	Mr. Bruce G. Unkel NAVSEA (Code 56Y15) Department of the Navy Washington, D.C. 20362-5101	1
9.	LT Dean C. Sugiyama 1339 Blue Falls Drive Chula Vista, California 92010	1

Thesis
S858255 Sugiyama
c.1 Nucelate pool boiling of R-114 and R-114/oil mixtures from single enchanced tubes.